APPENDIX C. OIL SPILL MODELING FOR EL SEGUNDO MARINE TERMINAL DRAFT ENVIRONMENTAL IMPACT REPORT

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April 9, 2007

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C.1. Introduction

The SIMAP (Spill Impact Model Application Package) model system, comprised of three-dimensional oil fate and biological effects models, was used for this study. The modeling was performed in probabilistic (stochastic) mode, with either randomly varying location along the shipping lanes or the fixed pipeline or alternate pipeline sites, spill date, and time, and environmental conditions during and after the release among potential conditions that would occur. The model results from these stochastic scenarios were analyzed to estimate mean, standard deviation, and 5th, 50th and 95th percentile results for surface water and shoreline oiling, water column and sediment contamination, and biological impacts (to wildlife, fish, invertebrates, and habitats).

Inputs to the oil spill model SIMAP include habitat and depth mapping, winds, currents, other environmental conditions, chemical composition and properties of the oils most likely to be spilled, specifications of the release (amount, location, etc.), toxicity parameters, and biological abundance. Model results are displayed by a Windows graphical user interface that animates the trajectory and concentrations over time. The figures included in this Appendix are snapshots taken from that output, synoptically (over time after the spill) showing the areas and volumes where oil or concentrations in the water would move if there were a spill of the assumed volume and conditions.

SIMAP was first run in stochastic mode for nine scenarios to estimate probabilities and degrees of oil exposure for each location in the vicinity of a spill (Table C.1-1) under a range of possible environmental conditions that could occur. These stochastic scenarios were used to determine probabilities of oil reaching various locations and to select worst-case runs for further study. Analysis of impacts for six other smaller-volume scenarios (in the same locations and with the same oil type) were made for the worst case runs based on the larger volume spill results by running the scenario with a smaller volume (2,500 bbl or 1,000 bbl spills). For the pipeline spills and operational releases at the Terminal, the release is assumed to occur at the ship in Berth 3 or Berth 4. A mid-point between them is used as the spill location (Figure C.1-1). Slight variation of the spill site in this vicinity would not significantly affect the model results. For in-transit scenarios, the spill location for each of the 100 runs was randomized along tanker routes to the terminal from the northbound and the southbound shipping lanes (Figure C.1-2).

Table C.1-1. Matrix of oil spill scenarios.

Scenario	Location	Oil type	Oil volume (bbl)	Release duration (hrs)
Terminal, diesel (ES-Pipe-1k-d)*	Terminal spill: Berths 3 and 4 (center point): 118^{o} 27.63' W; 33^{o} 55.12' N	Diesel	1,000	0.5
Terminal, light crude (ES-Pipe-1k-lc)*	Terminal spill: Berths 3 and 4 (center point): 118^{o} 27.63' W; 33^{o} 55.12' N	Arabian Light crude	1,000	0.5
Terminal, heavy crude (ES-Pipe-1k-hc)*	Terminal spill: Berths 3 and 4 (center point): 118^{o} 27.63' W; 33^{o} 55.12' N	Napo heavy crude	1,000	0.5
Terminal, diesel (ES-Pipe-11k-d)	Terminal spill: Berths 3 and 4 (center point): 118^{o} 27.63' W; 33^{o} 55.12' N	Diesel	11,000	1.5
Terminal, light crude (ES-Pipe-12k-lc)	Terminal spill: Berths 3 and 4 (center point): 118^{o} 27.63' W; 33^{o} 55.12' N	Arabian Light crude	12,090	0.9
Terminal, heavy crude (ES-Pipe-12k-hc)	Terminal spill: Berths 3 and 4 (center point): 118^{o} 27.63' W; 33^{o} 55.12' N	Napo heavy crude	12,090	0.9
Transit, diesel (ES-trans-d)	Shipping Lanes: Randomize along paths in Figure C.1-1.	Diesel	275,000	4
Transit, light crude (ES-trans-lc)	Shipping Lanes: Randomize along paths in Figure C.1-1.	Arabian Light crude	275,000	4
Transit, heavy crude (ES-trans-hc)	Shipping Lanes: Randomize along paths in Figure C.1-1.	Napo heavy crude	275,000	4
Transit, diesel, scaled (ES-trans-d-2K**)	Shipping Lanes: Randomize along paths in Figure C.1-1.	Diesel	2,500	4
Transit, light crude, scaled (ES-trans-lc-2K**)	Shipping Lanes: Randomize along paths in Figure C.1-1.	Arabian Light crude	2,500	4
Transit, heavy crude, scaled	Shipping Lanes: Randomize	Napo heavy crude	2,500	4

Scenario	Location	Oil type	Oil volume (bbl)	Release duration (hrs)
(ES-trans-hc-2K**)	along paths in Figure C.1-1.			
Alternate, diesel (ES-alt-30k-d)	Alternative Berth: 118° 30.00' W; 33° 55.12' N	Diesel	30,000	2
Alternate, light crude (ES-alt-30k-lc)	Alternative Berth: 118° 30.00' W; 33° 55.12' N	Arabian Light crude	30,000	2.2
Alternate, heavy crude (ES-alt-30k-hc)	Alternative Berth: 118° 30.00' W; 33° 55.12' N	Napo heavy crude	30,000	2.2

* Analysis of impacts for these three scenarios were made for the worst case runs based on the 11,000 bbl diesel and 12,090 bbl light or heavy crude terminal spill results by running the scenarios with a volume of 1,000 bbl.

** Analysis of impacts for these three scenarios were made for the worst case runs based on the 275,000 bbl transit spill results by running the scenarios with a volume of 2,500 bbl.

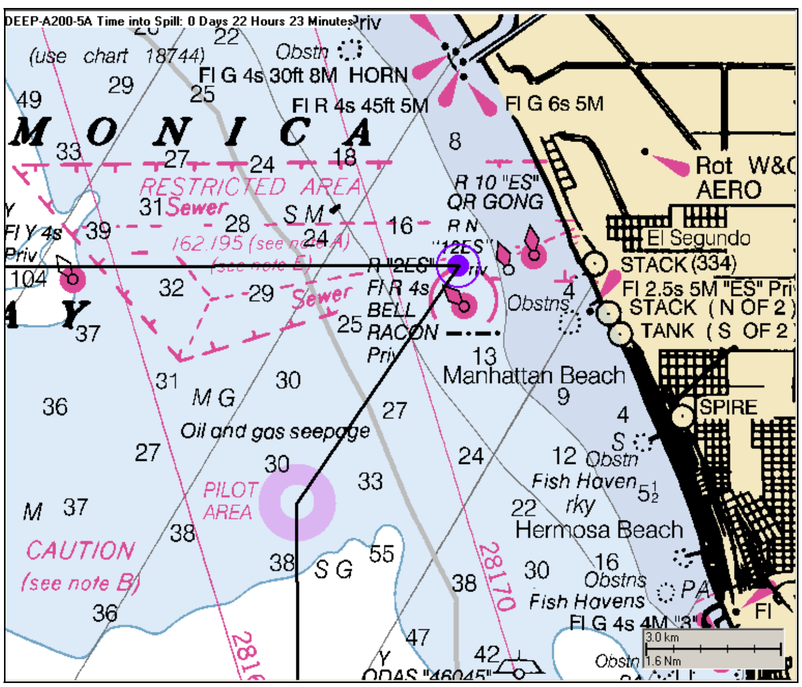

Figure C.1-1. Chart showing location of hypothetical pipeline spills near Berths 3 and 4.

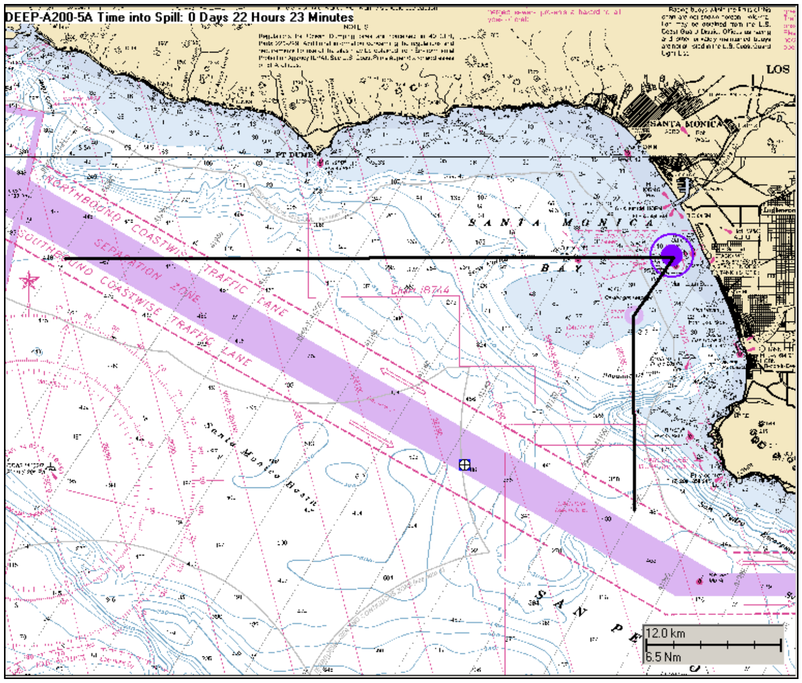

Figure C.1-2. Map of transit routes to and from the shipping lanes. Multiple spill runs will be randomized along the paths drawn in a heavy black line.

Table C.1-2 lists the time, date and location inputs for each of the 100 stochastic runs for the transit spill scenarios. The time and dates are the same for the terminal and alternate berth spills, however, the latitude and longitude for these scenarios are as described in Table C.1-1.

Table C.1-2. Time, date and location inputs for each of the 100 stochastic runs for the transit spills.

Run #	Year	Month	Day	Hour	Latitude (° N)	Longitude (° W)
1	1995	4	24	12	33.91846	118.87398
2	1997	4	21	18	33.91888	118.63904
3	2004	1	24	4	33.82626	118.49992
4	1998	8	30	0	33.73875	118.49921
5	1996	5	2	1	33.77454	118.49950
6	1999	8	13	17	33.91842	118.90078
7	1997	2	13	6	33.87250	118.49898
8	1999	11	21	13	33.91820	119.02393
9	1996	8	6	17	33.81509	118.49983
10	2004	3	18	0	33.91856	118.82152
11	2002	10	31	9	33.91858	118.80698
12	2004	5	12	14	33.91816	119.04288
13	1995	9	27	2	33.91846	118.87621
14	2005	5	18	23	33.91848	118.86324
15	2003	4	30	22	33.91914	118.49249
16	2001	1	19	11	33.77951	118.49954
17	2004	9	21	3	33.91872	118.72626
18	1995	9	15	16	33.91866	118.76575

Run #	Year	Month	Day	Hour	Latitude (° N)	Longitude (° W)
19	1999	8	23	23	33.91846	118.87775
20	1998	10	20	21	33.91869	118.74314
21	1999	7	14	17	33.91853	118.83723
22	2005	8	17	11	33.91853	118.83806
23	2003	3	22	21	33.91885	118.65645
24	2002	3	12	8	33.73220	118.49916
25	2000	4	17	13	33.78196	118.49957
26	2005	3	10	4	33.91885	118.65692
27	2004	1	30	21	33.91908	118.52454
28	1999	4	29	16	33.78913	118.49963
29	1996	9	20	0	33.91843	118.89228
30	1999	12	26	14	33.91858	118.80552
31	2004	6	2	12	33.71462	118.49902
32	1999	10	28	12	33.91913	118.49667
33	2005	9	26	7	33.91909	118.52149
34	2005	2	6	16	33.71835	118.49905
35	1998	7	29	1	33.91602	118.46336
36	2002	11	17	17	33.91871	118.73436
37	2000	10	30	4	33.90330	118.47377
38	2004	11	23	2	33.91912	118.50161
39	2003	3	29	2	33.91872	118.73074
40	1995	10	30	23	33.91845	118.87862
41	2004	5	29	22	33.91851	118.84818
42	2005	8	20	13	33.91822	119.01076
43	2003	12	3	4	33.90022	118.47630
44	2004	9	26	11	33.91817	119.04031
45	2000	5	3	9	33.85854	118.50019
46	1999	6	5	19	33.91833	118.94877
47	2001	2	6	22	33.91877	118.70132
48	2005	8	2	2	33.91853	118.83867
49	2001	11	17	15	33.91898	118.58430
50	2003	11	24	1	33.91824	119.00211
51	1995	5	7	7	33.91897	118.58979
52	2000	3	4	20	33.91822	119.00884
53	2005	3	2	10	33.91889	118.63348
54	2005	9	18	0	33.91875	118.71198
55	1997	12	5	8	33.91828	118.97558
56	2002	12	31	14	33.91911	118.50601
57	1995	3	29	3	33.91893	118.60865
58	2003	12	12	8	33.91842	118.90013
59	1996	3	10	10	33.86729	118.50026
60	1997	3	30	19	33.90836	118.46963
61	2000	2	21	16	33.90651	118.47114
62	1995	8	2	10	33.91824	118.99982
63	2004	5	14	17	33.79214	118.49965
64	2000	2	7	21	33.90611	118.47147
65	2003	8	18	19	33.91848	118.86428
66	1995	4	17	15	33.91860	118.79591
67	2002	5	15	4	33.91849	118.85960
68	1996	1	26	16	33.91863	118.78098
69	2002	7	3	15	33.72390	118.49909
70	2003	11	7	5	33.91891	118.61837
71	2003	1	15	11	33.88863	118.48578

Run #	Year	Month	Day	Hour	Latitude (° N)	Longitude (° W)
72	2005	3	25	10	33.91860	118.79551
73	2005	10	19	13	33.91895	118.60010
74	1995	1	30	17	33.91898	118.58223
75	2001	11	1	3	33.91861	118.79419
76	2000	4	21	10	33.91875	118.71332
77	2003	3	22	23	33.84024	118.50004
78	2004	12	10	23	33.91877	118.69826
79	2004	9	7	14	33.89622	118.47956
80	2000	1	28	16	33.91917	118.47530
81	2004	9	16	16	33.79866	118.49970
82	2005	8	30	22	33.86019	118.50021
83	2000	6	24	3	33.91840	118.90962
84	2001	9	16	5	33.88845	118.48592
85	2002	5	6	19	33.91819	119.02584
86	2005	3	21	2	33.72995	118.49914
87	2000	1	10	10	33.84581	118.50008
88	1997	5	11	21	33.91829	118.97453
89	2001	2	12	13	33.91846	118.87546
90	2004	6	7	14	33.91815	119.04936
91	2002	12	11	0	33.91869	118.74818
92	2005	2	9	14	33.91820	119.02209
93	2000	5	1	8	33.91914	118.49501
94	2003	10	21	15	33.80313	118.49974
95	2004	3	14	9	33.91912	118.50157
96	2000	4	7	4	33.78051	118.49955
97	2005	9	1	22	33.91893	118.61123
98	2002	4	18	12	33.88705	118.48707
99	2000	2	12	23	33.91834	118.94218
100	2001	3	20	17	33.91888	118.63834

The output of the stochastic model includes time histories of a large number of spill trajectories. These distributions are used to (1) estimate the percent of these hypothetical spills where water surface, water column, and shoreline areas will be affected by a release; (2) determine the highest exposure concentration in time and for any possible environmental condition; and (3) identify the worst-case runs out of 100 randomly-selected events that either, had the most impact on selected sensitive sites, oiled the most shoreline on the mainland, or had the most impact on the water column.

For the twelve stochastic scenarios modeled, three of which were scaled, 100 simulations were run for a given spill location or shipping route and oil, varying the spill date and time, and thus the environmental conditions, for each run. The results of each scenario were sorted by the worst case run criteria: 1) the number of critical resource areas that were hit on the California mainland, 2) the number of critical resource areas that were hit on the islands along the Santa Barbara Channel, and 3) the percent of oil impacting the water column. These results were then were evaluated in detail.

C.2 Model Input Data

C.2.1 Geographical and Model Grid

For geographical reference, SIMAP uses a rectilinear grid to designate the location of the shoreline, the water depth (bathymetry), and the shore or habitat type. The grid is generated from a digital coastline using the ESRI Arc/Info compatible Spatial Analyst program. The cells are then coded for depth and habitat type. Note that the model identifies the shoreline using this grid. Thus, in model outputs, the coastline map is only used for visual reference; it is the habitat grid that defines the actual location of the shoreline in the model.

The digital shoreline, shore type, and habitat mapping for the Southern California were obtained from Environmental Sensitivity Index (ESI) Atlas database compiled for the area by Research Planning, Inc. (RPI). These data are distributed by NOAA Hazmat (Seattle, WA). Additional data on shore types and locations of wetlands were provided by MBC Applied Environmental Sciences.

Habitats within the grid are designated as landward or seaward. Landward portions are the shelf areas <200m deep. The seaward portion is the more oceanic water >200m deep. This designation allows different biological abundances to be simulated in landward and seaward zones of the same habitat type (e.g., open water with sand bottom). The biological database is coded to landward or seaward by species (see French et al., 1996).

Ecological habitat types (Table C.2-1) are broadly categorized into two zones: intertidal and subtidal. Intertidal habitats are those above spring low water tide level, with subtidal being all water areas below that level. Intertidal areas may be extensive, such that they are wide enough to be represented by an entire grid cell at the resolution of the grid. These are typically either mud flats or wetlands, and are coded 20 (seaward mudflat), 21 (seaward wetland), 50 (landward mudflat) or 51 (landward wetland). All other intertidal habitats are typically much narrower than the size of a grid cell. Thus, these fringing intertidal types (indicated by F in Table 3-1) have typical (for the region, French et al., 1996) widths associated with them in the model. Boundaries between land and water are fringing intertidal habitat types. On the waterside of fringing intertidal grid cells, there may be extensive intertidal grid cells if the intertidal zone is extensive. Otherwise, subtidal habitats border the fringing intertidal.

Table C.2-1. Classification of habitats. Seaward (Sw) and landward (Lw) system codes are listed. (Fringing types indicated by (F) are only as wide as the intertidal zone in that province. Others (W = water) are a full grid cell wide and must have a fringing type on the land side.)

Habitat Code (Sw,lw)	Ecological Habitat	F or W
Intertidal		
1,31	Rocky Shore	F
2,32	Gravel Beach	F
3,33	Sand Beach	F
4,34	Fringing Mud Flat	F
5,35	Fringing Wetland (Saltmarsh)	F
6,36	Macrophyte Bed	F
7,37	Mollusk Reef	F
8,38	Coral Reef	F
Subtidal		
9,39	Rock Bottom	W
10,40	Gravel Bottom	W
11,41	Sand Bottom	W
12,42	Silt-mud Bottom	W
13,43	Wetland (Subtidal of Saltmarsh)	W
14,44	Macroalgal (Kelp) Bed	W
15,45	Mollusk Reef	W
16,46	Coral Reef	W
17,47	Seagrass Bed	W
	Intertidal	
18,48	Man-made, Artificial	F
19,49	Ice Edge	F
20,50	Extensive Mud Flat	W
21,51	Extensive Wetland (Saltmarsh)	W

The intertidal habitats were assigned based on the shore types in the ESI Atlas. These data were gridded using the ESRI Arc/Info compatible Spatial Analyst program. Open water areas were defaulted to sand bottom, as open water bottom type has no influence on the model results. Where data are missing, shore types are defaulted as in Table C.2-2.

Table C.2-2. Default fringing intertidal habitat type, given adjacent subtidal or extensive intertidal habitat type.

Subtidal or Extensive Intertidal Habitat	Fringing Intertidal Habitat
Seagrass Bed (47)	Sand Beach (33)
Subtidal Sand Bottom (41)	Sand Beach (33)
Extensive Mudflat (50)	Fringing Mudflat (34)
Extensive Wetland (51)	Fringing wetland (35)

Depth data for the offshore and coastal waters were obtained from Hydrographic Survey Data supplied on CD-ROM by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Geophysical Data Center. Hydrographic survey data consist of large numbers of individual depth soundings. The depth soundings were interpolated into the model grid for each area, by averaging all soundings falling within a cell. The gridded habitat and depth data are shown in the Figures C.2-1 to C.2-7.

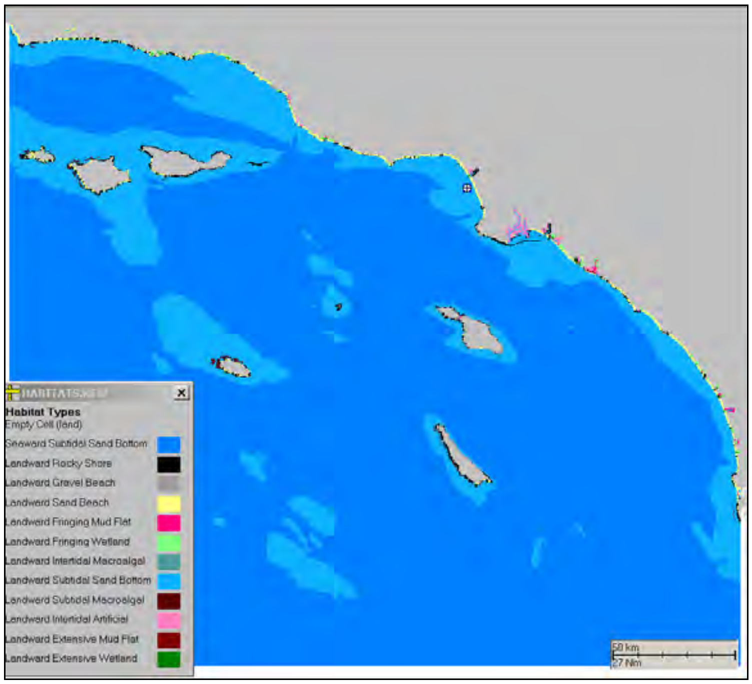

Figure C.2-1. Habitat grid used for modeling the potential spills.

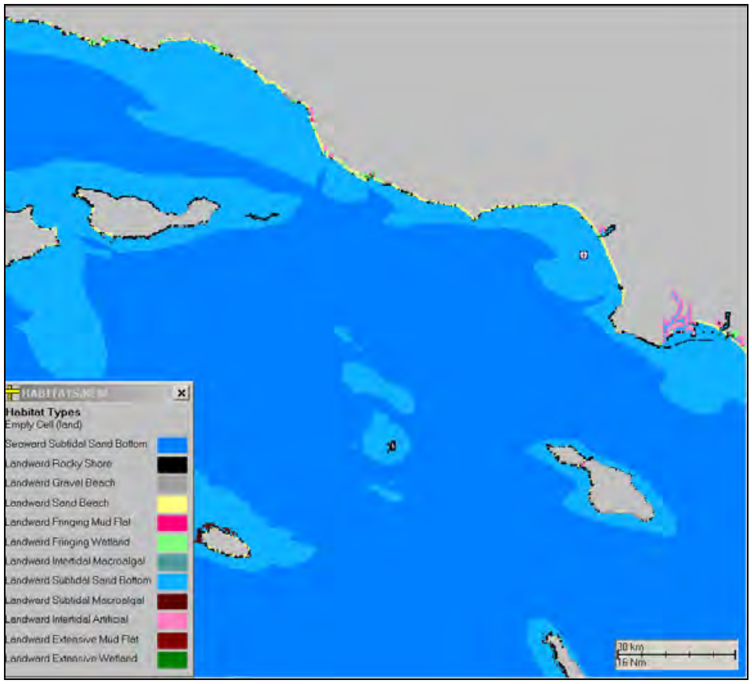

Figure C.2-2. Habitat grid used for modeling the potential spills (closer view).

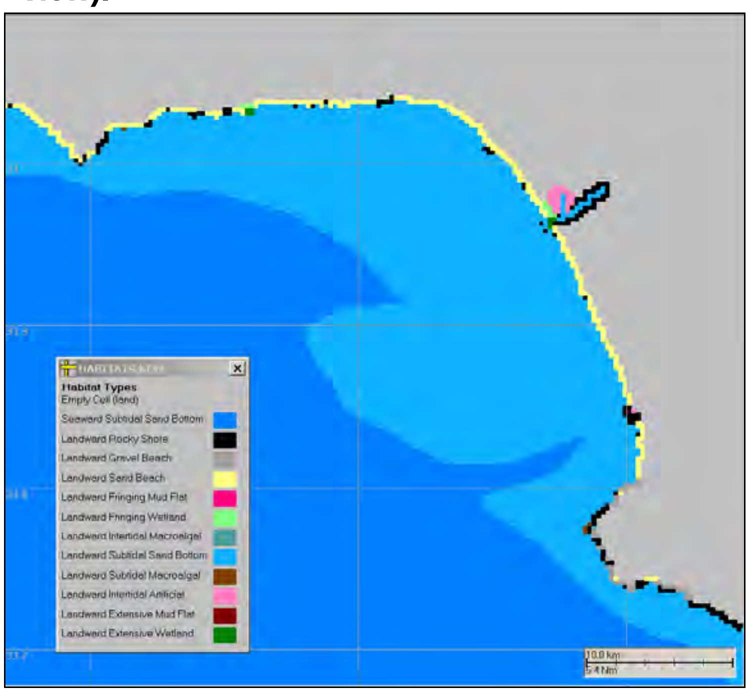

Figure C.2-3. Habitats within Santa Monica Bay.

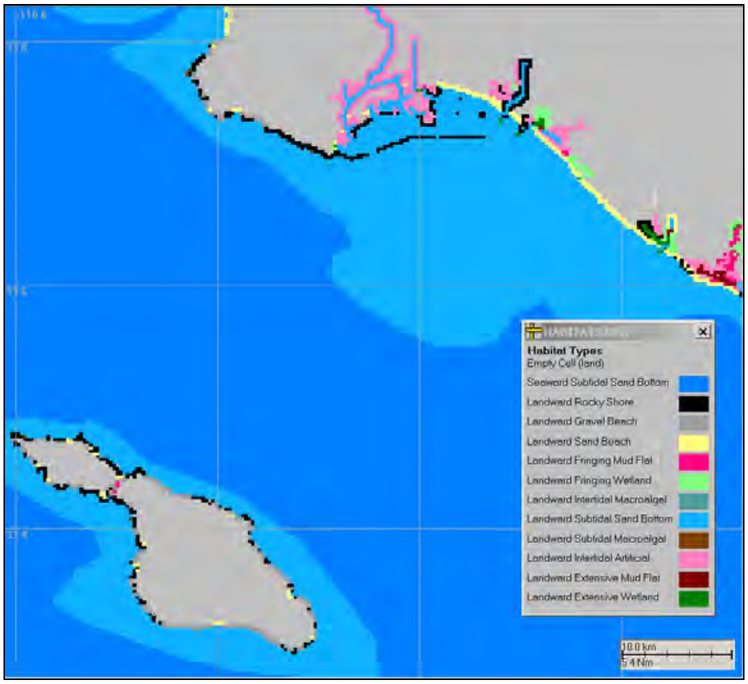

Figure C.2-4. Habitats within the Long Beach to Catalina area.

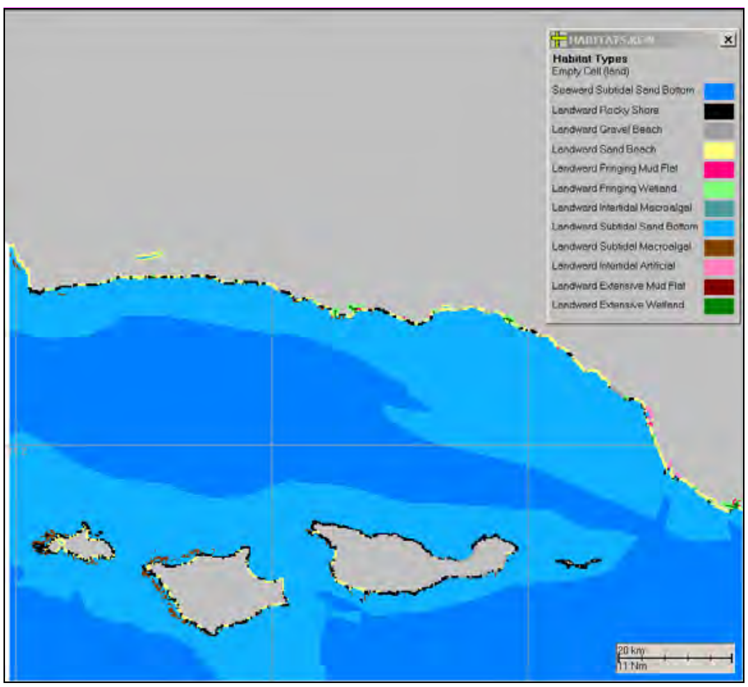

Figure C.2-5. Habitats along Channel Islands and Santa Barbara Channel.

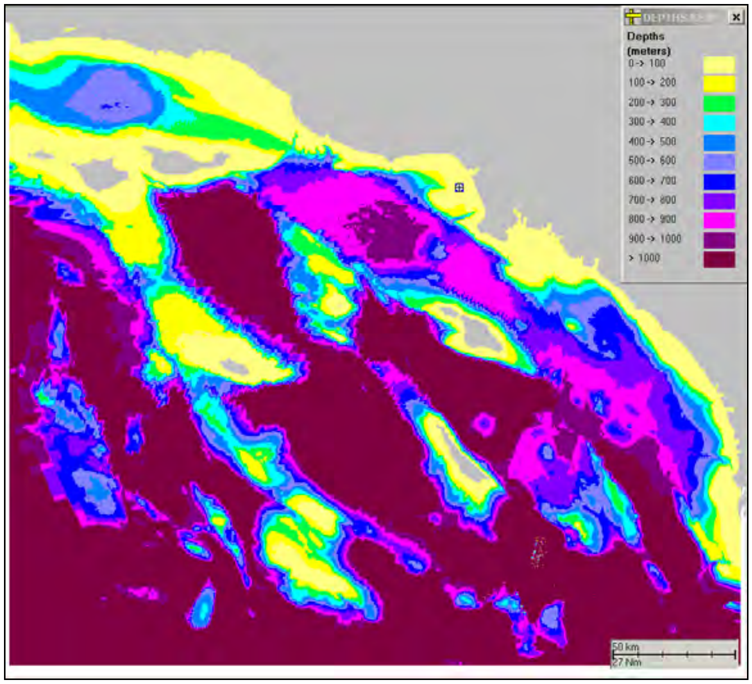

Figure C.2-6. Depth grid used for modeling the potential spills.

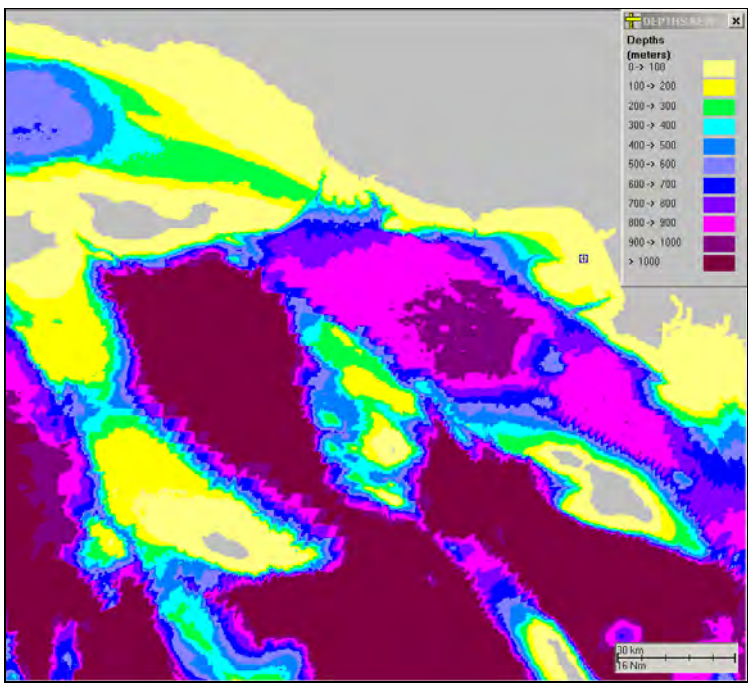

Figure C.2-7. Depth grid used for modeling the potential spills (closer view).

Table C.2-3 shows the dimensions of the habitat grid that was used for all scenarios.

Table C.2-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs.

Habitat grid	ELSEGUNDO-3.HAB
Grid W edge	120^{o} 30' 44.35"'W
Grid S edge	32^{o} 7' 38.23" N
Cell size (^{o}longitude)	0.00327^{o} W
Cell size (^{o}latitude)	0.002411^{o} N
Cell size (m) west-east	307.42
Cell size (m) south-north	267.64
# cells west-east	1,000
# cells south-north	1,000
Water cell area (m^2)	82,278.24
Shore cell length (m)	286.84
Shore cell width – Rocky shore (m)	2.0
Shore cell width – Artificial shore (m)	0.10
Shore cell width – Gravel beach (m)	2.0
Shore cell width – Sand beach (m)	10.0
Shore cell width – Mud flat (m)	120.0
Shore cell width – Wetlands (fringing,m)	120.0

C.2.2 Environmental Data

The model uses hourly wind speed and direction for the time of the spill and simulation. A 10-year wind record was sampled at random to develop a probability distribution of environmental conditions that might occur at the time of a spill. Data from the National Data Buoy Center (NDBC) buoy 46025 in Santa Monica Basin, were used for all scenarios.

Table C.2-4. Wind data used for all stochastic scenarios.

File Name	Location	Latitude Longitude	Dates	Data Source
46025-95-05-PST.WNE	BUOY 46025 Santa Monica Basin	33.75 ºN 119.08 ºW	1995-2005	National Data Buoy Center

Wind data were downloaded from one NDBC buoy (BUOY 46025 Santa Monica Basin). Figure C.2-8 displays where the buoy is located relative to the spill locations. The data start on 8 January 1995 and end on 31 December 2005.

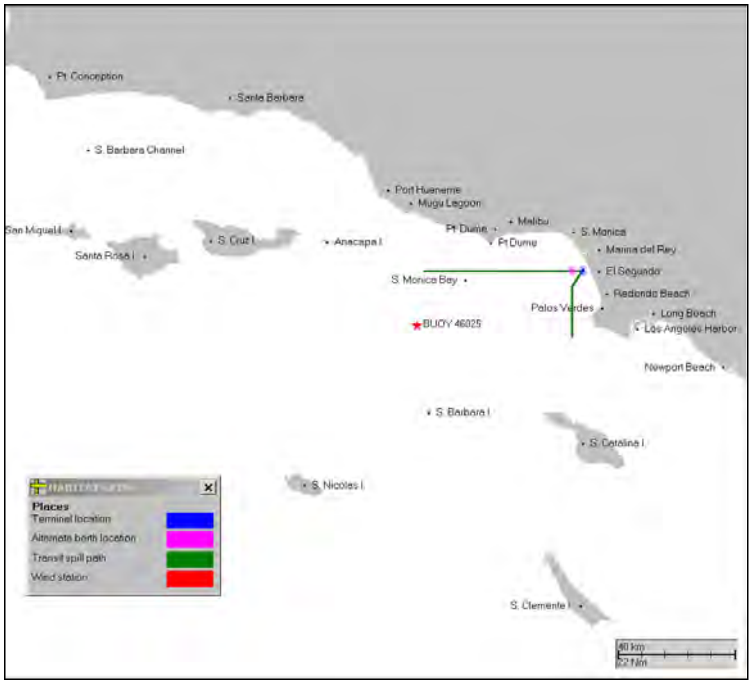

Figure C.2-8. Map of the vicinity of the potential spill locations and wind buoy location.

Surface water temperature varies by month, based on data for California waters in French et al. (1996). The air immediately above the water is assumed to have the same temperature as the water surface, this being the best estimate of air temperature in contact with floating oil.

Table C.2-5. Water temperature by month of the year (from French et al., 1996).

Month	Surface Water Temperature (^oC)	Bottom Water Temperature (^oC)	Pycnocline Depth (m)
January	15	15	15
February	12	12	12
March	20	20	20
April	15	15	15
May	12	12	12
June	20	20	20
July	15	15	15
August	12	12	12
September	20	20	20
October	15	15	15
November	12	12	12
December	20	20	20

Salinity is assumed to be the mean value for the location of the spill site, based on data compiled in French et al. (1996). The salinity for surface and bottom waters was assumed to be 33 ppt. The salinity value assumed in the model runs has little influence on the fate of the oil, as salinity is used to calculate water density (along with temperature), which is used to calculate buoyancy, and none of the oils evaluated have densities near that of the water.

Suspended sediment is assumed to be 10 mg/l, a typical value for coastal waters (Kullenberg, 1982). The sedimentation rate is set at 1 m/day. These default values have no significant affect on the model trajectory. Sedimentation of oil and PAHs becomes significant at about 100 mg/L suspended sediment concentration. There is no indication that high suspended sediment concentrations would occur in any of the areas where spills were simulated.

The horizontal diffusion (randomized mixing) coefficient is assumed as 1 m^2/sec. The vertical diffusion (randomized mixing) coefficient is assumed to be 0.0001 m^2/sec. These are reasonable values for coastal waters based on empirical data (Okubo and Ozmidov, 1970; Okubo, 1971) and modeling experience.

A summary of the inputs to the fates model for all scenarios is shown in Table C.2-6.

Table C.2-6. Inputs to the Fates Model for Stochastic Scenarios

Name	Description	Units	Source(s) of Information	Value(s)
Number of runs	Number of random start times to run in stochastic mode	#	-	100
Initial number of surface spillets	Initial number of Lagrangian elements used to simulate mass floating on the surface	#	-	200
Number of aromatic spillets	Number of Lagrangian elements used to simulate dissolved aromatics in the water	#	-	2,000
Fates Output Threshold: floating on water surface	Slick or surface mass thickness passing through a grid cell	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: shoreline	Total hydrocarbons deposited on shorelines, averaged over each habitat grid cell.	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: dissolved aromatics in water or sediment	Dissolved concentration of aromatics with $\log(K_{ow}) \leq 5.6$ (bioavailable fraction)	mg/m^3 = $\mu g/L$ = ppb	Below minimum for effects to sensitive species exposed for at least two weeks	1

Name	Description	Units	Source(s) of Information	Value(s)
Fates Output Threshold: Subsurface (water) total hydrocarbons	Concentration of total hydrocarbons in droplets	mg/m^3 = $\mu g/L$ = ppb	Minimum value with no potential for impact	10
Fates Output Threshold: Sediment total hydrocarbons	Total hydrocarbon loading to sediments, averaged over each habitat grid cell.	g/m^2	Minimum value with no potential for impact	0.0001 g/m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)
Salinity	Surface water salinity	ppt	French et al. (1996) province 41	33
Surface Water Temperature	Water temperature at the sea surface	Degrees C	French et al. (1996) province 41	monthly means (see Table C.2-6)
Subsurface Water Temperature	Water temperature for subsurface	Degrees C	French et al. (1996) province 41	monthly means (see Table C.2-6)
Air Temperature	Air water temperature at water surface	Degrees C	(assume = water temperature)	(= water temperature)
Fetch	Fetch = distance to land to N, S, E, W (if landfall not in model domain)	km	Chart	(calculated from model grid)
Wind drift speed	Speed oil moves down wind relative to wind	% of wind speed	Youssef (1993); Youssef and Spaulding (1993)	(model calculated)
Wind drift angle	Angle to right of wind (in northern hemisphere) that oil drifts	Deg. to right of down wind	Youssef (1993); Youssef and Spaulding (1993, 1994)	(model calculated)
Horizontal turbulent diffusion coefficient	Randomized turbulent mixing parameter in x & y	m^2/sec	French et al. (1996) based on Okubo (1971)	1 m^2/sec (estuaries and low energy coastal areas)
Vertical turbulent diffusion coefficient	Randomized turbulent mixing parameter in z	m^2/sec	French et al. (1996) based on Okubo (1971)	0.0001 m^2/sec
Suspended sediment concentration	Average suspended sediment concentration during spill period	mg/l	French et al. (1996)	10 mg/l
Suspended sediment settling rate	Net settling rate for suspended sediments	m/day	French et al. (1996)	1 m/day

C.2.3 Currents

Mean offshore currents for January, March, May, July, September, and November were compiled using data from California Cooperative Oceanic Fisheries Investigations Atlas No. 4 (State of California Marine Research

Committee, 1966). Data was taken from maps showing mean monthly geostrophic flow off the coast of California for the years 1950-1965. These maps contain contour lines showing ocean surface topography. The current files were created by marking points along each of the contour lines and placing corresponding current vectors at those points. The magnitude of the current vectors was determined by measuring the distance between adjacent contour lines and estimating the current velocity using a conversion chart provided in the atlas. Once these vectors were entered into a grid, a vector spreading algorithm filled in the vectors for the remainder of the gridded area. The current velocities are estimates and have an error margin of roughly ± 5 cm/s.

C.2.4 Oil Properties, Toxicity, and Impact Thresholds

Since oil density largely controls the fate and impacts of discharged oil, the modeling design was to run crude oil types spanning the range of crude oil densities (i.e., the API range) that might be refined at El Segundo in the future. The two crude oils that were modeled were Arabian light crude and Napo heavy crude. Diesel oil spills were modeled to evaluate spills of products produced at and shipped from the El Segundo facility. Diesel would cause the most impacts to natural resources of products produced.

Light crude

Properties for light crude oil are for Arabian light crude, based on data in Environment Canada's Oil Property Catalogue (www.etcentre.org/spills). In 2005, as part of a project for California Fish and Game (OSPR), we had asked Chevron for the most likely light crude to be shipped (which was said to be Arabian light crude) and obtained data from Chevron on the properties of Arabian Light (Saudi oil). However, Environment Canada recently updated their oil database with Arabian Light crude, which has similar properties to that Chevron provided (non-significant differences). Because the Environment Canada database had additional parameters needed (e.g., C3 benzene content), and more detail on the boiling curve, as well as that fact that the Environment Canada database is published/publicly available, the Environment Canada database oil properties were used in the model runs. The key properties at the standard temperature of $25^{o}C$ were: density = 0.8641 g/cm^3, viscosity = 13 cp, oil-water surface tension = 21.6 dyne/cm and maximum mousse water content =90%.

Table C.2-7. Oil properties for Arabian Light crude oil assumed in the modeling.

Property	Value	Reference
Density @ 25^{o}C (g/cm3)	0.862	Jokuty et al. (1999)[1]
API gravity	33.4	Jokuty et al. (1999)[1]
Viscosity @ 25^{o}C (cp)	9.8	Jokuty et al. (1999) [1]
Surface Tension (dyne/cm)	20.4	Jokuty et al. (1999) [1]
Pour Point (deg. C)	-30	Jokuty et al. (1999) [1]
Fraction monoaromatic hydrocarbons (MAHs, 1-ring aromatics)	0.015420	Jokuty et al. (1999) [1]
Fraction 2-ring polynuclear aromatic hydrocarbons (2-ring PAHs)	0.011930	Jokuty et al. (1999) [1]
Fraction 3-ring polynuclear aromatic hydrocarbons (3-ring PAHs)	0.016313	Jokuty et al. (1999) [1]
Fraction Non-Aromatic Volatiles: boiling point < 180^{o}C	0.174580	Jokuty et al. (1999)[2]
Fraction Non-Aromatic Volatiles: boiling point 180-264^{o}C	0.135070	Jokuty et al. (1999)[2]
Fraction Non-Aromatic Volatiles: boiling point 264-380^{o}C	0.184687	Jokuty et al. (1999)[2]
Minimum Oil Thickness (m)	0.000010	McAuliffe (1987)
Maximum Mousse Water Content (%)	87	Jokuty et al. (1999) [1]

[1] – Data from the Environment Canada Oil Property Database, which is available on the web (http://www.etcentre.org/spills) and described in Jokuty et al. (1999).
[2] – Total hydrocarbon data was taken from the Environment Canada Oil Property Database. The aromatic hydrocarbon fraction was subtracted from the total hydrocarbon fraction to obtain the aliphatic fraction.

Diesel

Properties of typical diesel are in Table C.2-8.

Table C.2-8. Oil properties for Diesel assumed in the modeling.

Property	Value	Reference
Oil name		Diesel Fuel Oil (California)
Density @ 25°C (g/cm3)	0.83	Jokuty et al. (1999)[1]
API gravity	38.8	Jokuty et al. (1999)[1]
Viscosity @ 25°C (cp)	2	Jokuty et al. (1999)[1]
Surface Tension (dyne/cm)	27.4	Jokuty et al. (1999)[1]
Pour Point (deg. C)	-36	Jokuty et al. (1999)[1]
Fraction monoaromatic hydrocarbons (MAHs)	0.023336	Jokuty et al. (1999)[1]
Fraction polynuclear aromatic hydrocarbons (PAHs)	0.012151	Lee et al. (1992)
Fraction 2-ring aromatics (included in PAHs above)	0.010175	Lee et al. (1992)
Fraction 3-ring aromatics (included in PAHs above)	0.001976	Lee et al. (1992)
Fraction Non-Aromatic Volatiles: boiling point < 180°C	0.186664	Jokuty et al. (1999)[2]
Fraction Non-Aromatic Volatiles: boiling point 180-264°C	0.426825	Jokuty et al. (1999)[2]
Fraction Non-Aromatic Volatiles: boiling point 264-380°C	0.000000	Jokuty et al. (1999)[2]
Minimum Oil Thickness (m)	0.000010	McAuliffe (1987)
Maximum Mousse Water Content (%)	0	Jokuty et al. (1999)[1]

[1] – Data from the Environment Canada Oil Property Database, which is available on the web (http://www.etcentre.org/spills) and described in Jokuty et al. (1999).
[2] – Total hydrocarbon data was taken from the Environment Canada Oil Property Database. The aromatic hydrocarbon fraction was subtracted from the total hydrocarbon fraction to obtain the aliphatic fraction.

Heavy Crude

NAPO Export Blend 2005 is used to characterize heavy crude oils refined at El Segundo. Characteristics used are in Table C.2-9.

Table C.2-9. Oil properties for heavy crude oil assumed in the modeling.

Property	Value	Reference
Oil name		NAPO Export Blend 2005
Density @ 25°C (g/cm3)	0.93958	Chevron (Sep 2006)
API gravity	19.1	Chevron (Sep 2006)
Viscosity @ 25°C (cp)	878	Chevron (Sep 2006)[1]
Surface Tension (dyne/cm)	26.6	ADIOS (2000) [2,4]
Pour Point (deg. C)	-4.9	Chevron (Sep 2006)
Fraction monoaromatic hydrocarbons (MAHs, 1-ring aromatics)	0.041789	Chevron (Sep 2006)[3]
Fraction 2-ring polynuclear aromatic hydrocarbons (2-ring PAHs)	0.062063	Chevron (Sep 2006)[3]
Fraction 3-ring polynuclear aromatic hydrocarbons (3-ring PAHs)	0.109858	Chevron (Sep 2006)[3]
Fraction Non-Aromatic Volatiles: boiling point < 180°C	0.062878	Chevron (Sep 2006)[3]
Fraction Non-Aromatic Volatiles: boiling point 180-264°C	0.028026	Chevron (Sep 2006)[3]
Fraction Non-Aromatic Volatiles: boiling point 264-380°C	0.138240	Chevron (Sep 2006)[3]
Minimum Oil Thickness (m)	0.0010	McAuliffe (1987)
Maximum Mousse Water Content (%)	74	Jokuty et al. (1999) [2]

[1] – Value from Chevron at 40°C was corrected to 25°C (and translated from cSt to cp). Temperature conversion equation from: Reid, R.C., Prausnitz, J.M., Poling, B.E. The Properties of Gases and Liquids. McGraw-Hill, Inc., New York.
[2] – Value for Oriente crude, another Ecuadorian crude, from the Environment Canada Oil Property Database, which is available on the web (http://www.etcentre.org/spills) and described in Jokuty et al. (1999).
[3] – Based on percentage aromatics in distillation cuts of the appropriate boiling point range.
[4] –Used Naphthenes and Aromatic data to determine total Aromatic fractions. Subtracted Aromatics from Total Yield fractions to obtain Aliphatic fractions. Used Lt Gasoline, Lt Naphtha and half of Hvy Naptha for Group 1. Used half of Hvy Naptha and Kerosene for Group 2. Used Atm Gas Oil and Lt Vac Gas Oil for Group 3. To determine aromatic and aliphatic amount in Group 1 used same aromatic to aliphatic ratio as in Groups 2 and 3 because there was no aromatic data for Lt Gasoline.
[4] – Selected proxy oil with similar oil properties.

C.2.4.1 Whole oil

French et al. (1996) reviewed the literature regarding the necessary dose to affect birds and other wildlife. This was translated to a minimum thickness of floating oil for effects on wildlife, which is 10 g/m^2 (10 micron thick oil).

The threshold for effects on intertidal vegetation has been observed to be much higher than this level (by 2-3 orders of magnitude, French et al., 1996). On the other hand, intertidal invertebrates have been observed to be more sensitive than vegetation. Thus, 100 g/m^2 was assumed as the threshold for effects on fauna due to smothering and/or toxic exposures of oil in intertidal habitats.

Whole oil droplets in the water column may affect fish and invertebrates by interfering with feeding or clogging gills. However, data quantifying a threshold level for effects has not been identified. A conservative threshold of 10 ppb for fish and invertebrates was used in the modeling as a minimum for inclusion in model outputs. This level is based on literature reviewed by Markarian et al. (1993) and French et al. (1996).

C.2.4.2 Low molecular weight aromatics

For crude oil, diesel and heavy fuel oil spills at the water surface, MAHs do not have a significant impact on aquatic organisms for the following reasons. MAH concentrations are typically $\leq$3% in fresh oils. MAHs are soluble, and so some becomes bioavailable (dissolved). MAH compounds are also very volatile, and will volatilize (from the water surface and water column) very quickly after a spill. The threshold for toxic effects for these compounds is about 500 ppb for sensitive species (French McCay, 2002). MAHs evaporate faster than they dissolve, such that toxic concentrations are not reached. The small concentrations of MAHs in the water will quickly be diluted to levels well below toxic thresholds immediately after a spill. Thus, the assumed values for MAH concentrations in the oil, as well as their fates, have little influence on model results. The percentage of PAHs has a significant influence on the model results. Thus, the LC50s used in the modeling analysis were for total dissolved PAH concentrations in the water ($LC50_{mix}$).

To estimate $LC50_{mix}$ values for dissolved PAHs in the water, the additive model described in French McCay (2002) was used. French McCay (2002) estimated $LC50_{mix}$ = 50 ppb for typical fuels at infinite exposure time and for the average species. Ninety-five percent of species have LC50s between 6 and 400 μg/L (ppb). In the assessment of impacts, all species are assumed to be of high sensitivity to oil hydrocarbons, i.e., 6 ppb was used in the analysis to evaluate worst-case impacts for water column biota.

The LC50s above are for the concentration of *dissolved* PAHs that would be lethal to 50% of exposed organisms for a long enough times of exposure for mortality to occur. For PAHs, this is for at least 2 weeks of exposure at warm temperature. For chemicals in general, toxicity is higher, and the LC50 lower, at longer time of exposure and higher temperature (French et al, 1996; French McCay, 2002). The model corrects this LC50 to temperature and duration of exposure for each group of organisms exposed.

C.2.4.3 Toxicity Thresholds of Concern

The literature shows that, for most organic and inorganic chemicals, the threshold for sublethal effects is approximately 10 times lower than the 96-hour LC50 (Call et al., 1985; Gobas, 1989; Giesy and Graney, 1989). The only chemicals where higher ratios occur are those that have very high log(K_{ow}), and so bioaccumulate. PAHs have ratio of up to 10. Thus, the sublethal effect threshold for PAHs in oils would be about 1 ppb. Dissolved PAH concentrations below 1 ppb would not be expected to have toxic effects on aquatic organisms. Note that exceedance of the chronic threshold would need to be for long time periods (>1 week) for effects to occur.

The model results show that the duration of water column exposures are on the order of hours. Thus, the exposures are acute rather than long-term, and the LC50 for infinite exposure time is very conservative in considering potential for effects. Sublethal effects would also be expected to vary by duration of exposure. Table C.2-10 lists acute toxicity values for soluble fuel components in oil, and for sensitive (5th percentile) and average (50th percentile) species, at different durations of exposure at 25^{o}C (based on equations in French McCay, 2002). The LC50s for short exposure times are higher at colder temperatures (Figure C.2-9).

Table C.2-10. LC50s for fuel components and varying exposure times.

	BTEX (µg/l)	**C3 Benzenes (µg/l)**	**MAHs (µg/l)**	**PAHs (µg/l)**
Sensitive Species (2.5th percentile):				
LC50, 6 hours	1600	632	1190	99
LC50, 96 hours	506	136	374	9
LC50 (infinite exposure)	505	133	373	6
Average Species (50th percentile):				
LC50, 6 hours	13,400	5300	9920	789
LC50, 96 hours	4230	1140	3123	76
LC50 (infinite exposure)	4230	1115	3115	48

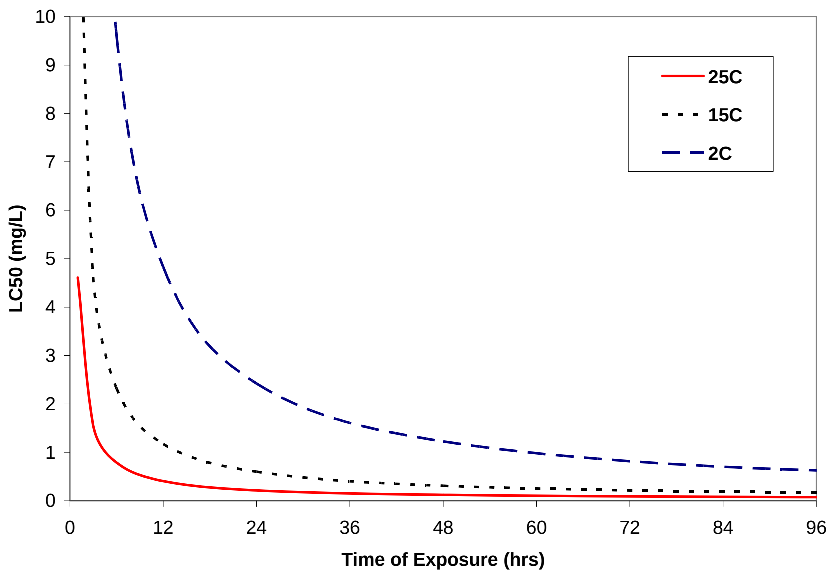

Figure C.2-9. LC50 of dissolved PAH mixtures from oil, as a function of exposure duration and temperature.

For PAHs, the LC50 for six hours of exposure for the 2.5th percentile species is 100 μg PAH/L (Table C.2-10). To account for variation among individuals of the sensitive species, 10% of this LC50 is assumed as the threshold for potential effects. Thus, to the nearest order of magnitude, peak exposure PAH concentrations below 10 ppb would have no significant impact on aquatic organisms for short exposure times.

The thresholds for effects were used in the stochastic model analysis to determine potential for impacts and the needed duration of model simulations. In the individual model runs and biological model analysis, the LC50 is corrected for temperature and time of exposure.

C.3 Maps of Exposure Probability and Mass

The results of multiple model runs of the nine scenarios (Table C.1-1) run in stochastic mode are evaluated to develop the following statistics, for each cell in the model grid ("location") and for each exposure index. Maps of results summarizing all 100 runs of a scenario are contained in this section. The mapped results presented include:

- Probability that the minimum threshold thickness or concentration will be exceeded at each location at any time following a spill. For surface oil thickness, the model records if any oil of greater than that thickness passes through the grid cell, regardless of the aerial coverage of the oil. For dissolved aromatic concentrations, the average concentration in the grid cell is used to determine if the threshold is exceeded. The probability for each location in the model grid is calculated as the percentage of runs where the threshold would be exceeded.
- Expected maximum mass (g/km^2) of surface oil at each location at any time following a spill. Note that all 100 spill runs are considered in this mapping, such that the entire area shown would not be impacted in a single event. The maps shows how much oil might reach each location, given a spill is transported in that direction.

The results have been separated by 2 seasons: 1) December to May, and 2) June to November, and are shown in the figures below. These figures indicate the probability of oiling and maximum oil exposure that could occur in each of the seasons.

Exposure indices and minimum thresholds (i.e., those less than values that might have an impact on any resource) used in the modeling were:

- Surface slick or floating oil: $\geq$ 0.01 g/m^2 (average thickness $\geq$ 0.01 micron)
- Shoreline: average mass loading over the shore segment (length of one grid cell, calculated as the cell diagonal length, times the typical width for the habitat type) $\geq$ 0.01 g/m^2
- Dissolved aromatics: average over the water cell $\geq$ 1 ppb (1 mg/m^3)

For the pipeline spills at the Terminal of 1,000 bbl diesel fuel oil, the footprint is the same as shown for the 11,000 bbl diesel spills, however the expected maximum mass (g/m^2) will be 9% of that shown in Figures C.3-1 to C.3-4. For the pipeline spills of 1,000 bbl light crude oil, the footprint is the same as shown for the 12,090 bbl light crude spill, however the mass (g/m^2) will be 8.3% of that shown in Figures C.3-5 to C.3-8. For the pipeline spills of 1,000 bbl heavy crude oil, the footprint is the same as shown for the 12,090 bbl heavy crude spill, however the mass (g/m^2) will be 8.3% of that shown in Figures C.3-9 to C.3-12.

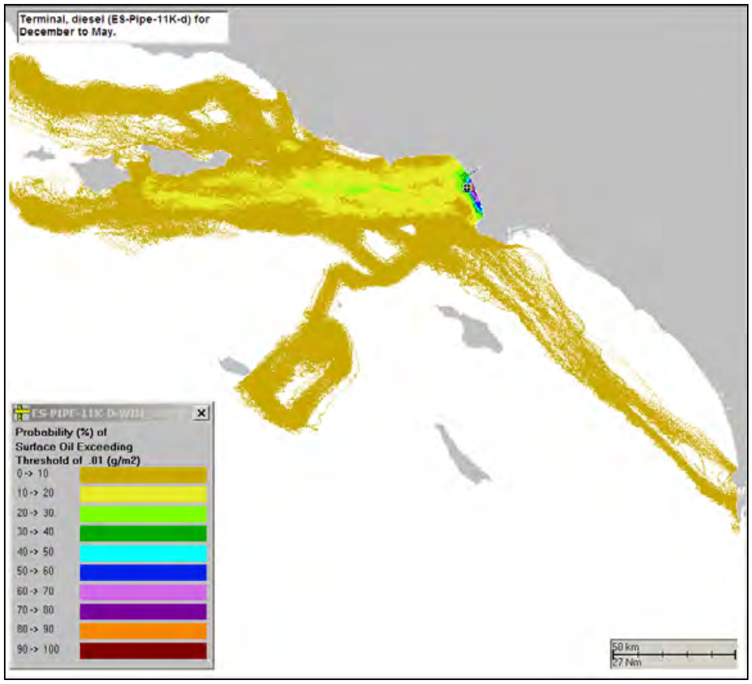

Figure C.3-1. **Terminal, diesel (ES-Pipe-11k-d): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for December to May.**

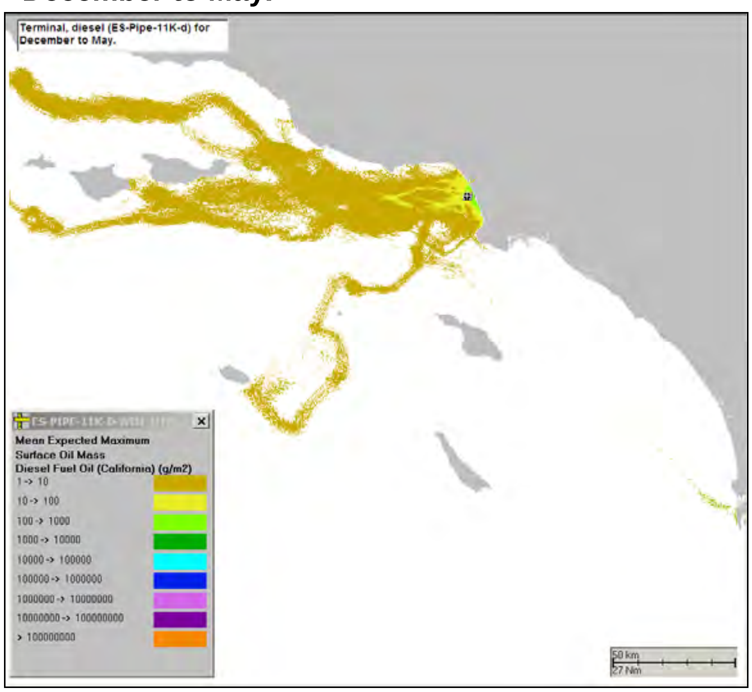

Figure C.3-2. **Terminal, diesel (ES-Pipe-11k-d): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for December to May.**

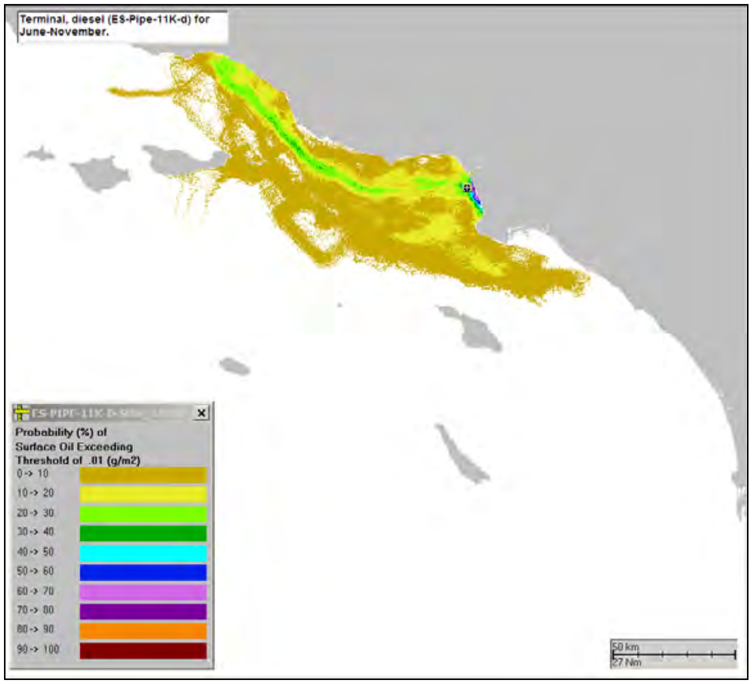

Figure C.3-3. Terminal, diesel (ES-Pipe-11k-d): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for June to November.

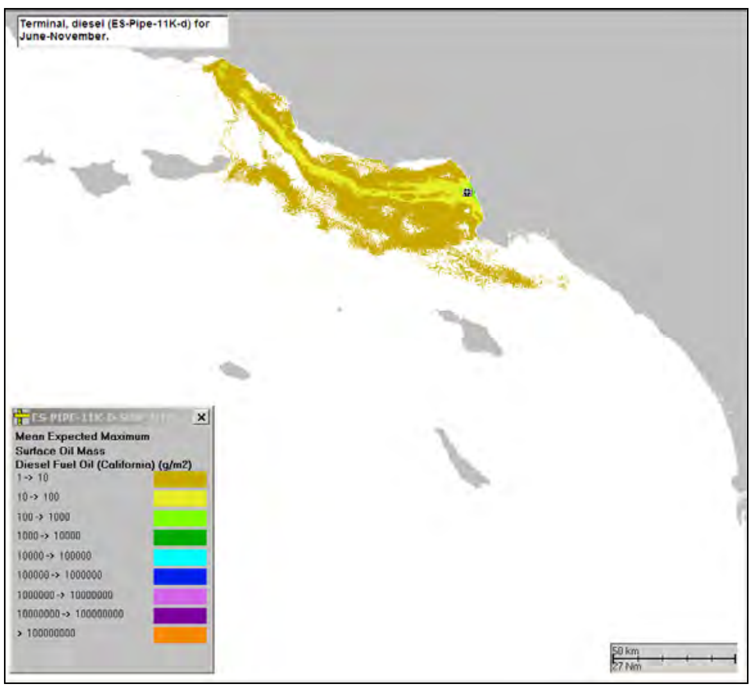

Figure C.3-4. Terminal, diesel (ES-Pipe-11k-d): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for June to November.

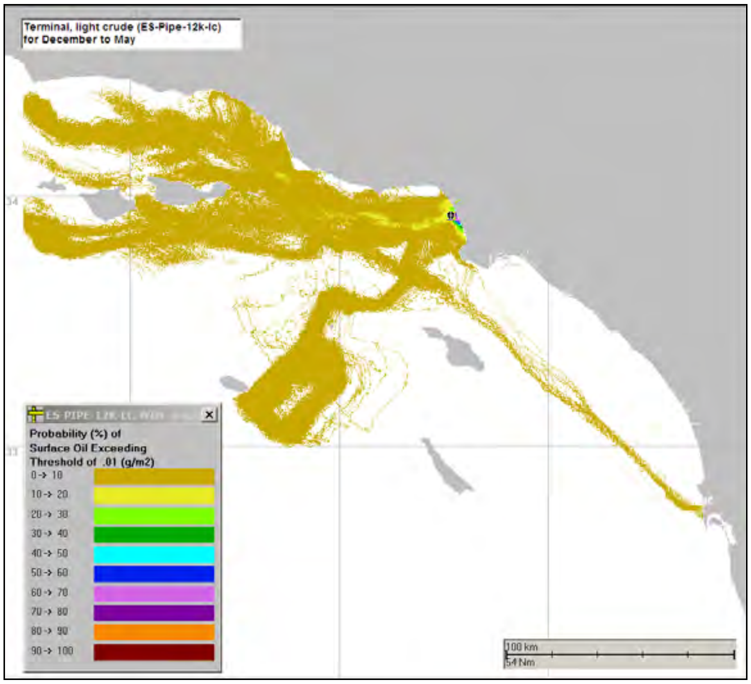

Figure C.3-5. Terminal, light crude (ES-Pipe-12k-lc): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for December to May.

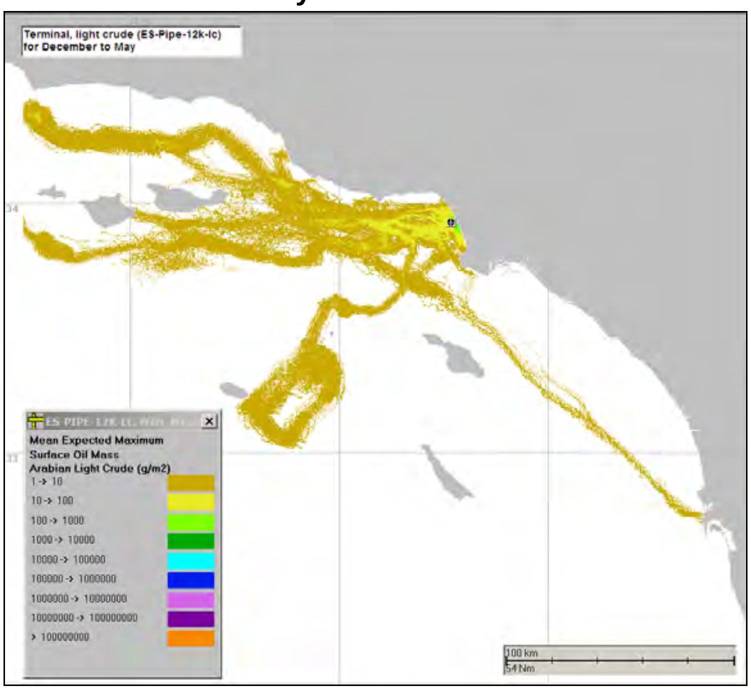

Figure C.3-6. Terminal, light crude (ES-Pipe-12k-lc): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for December to May.

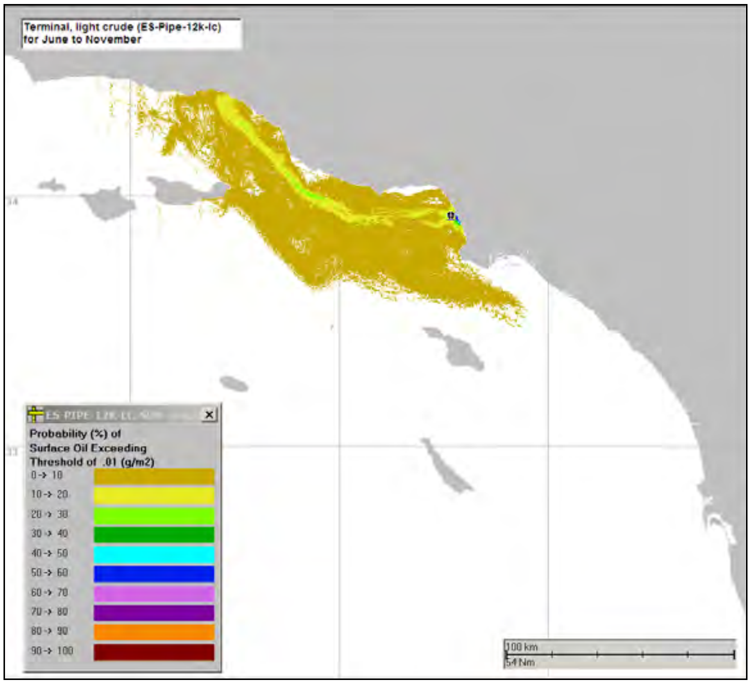

Figure C.3-7. Terminal, light crude (ES-Pipe-12k-lc): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for June to November.

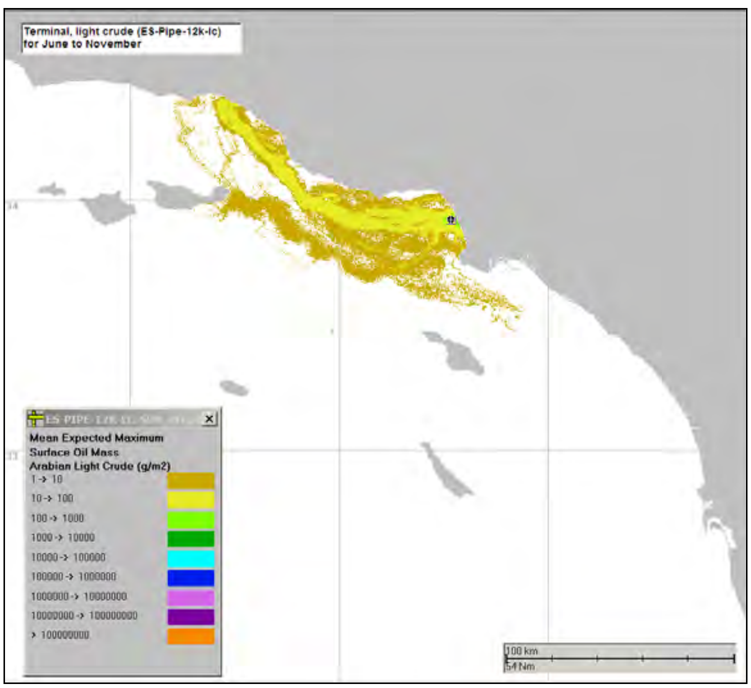

Figure C.3-8. Terminal, light crude (ES-Pipe-12k-lc): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for June to November.

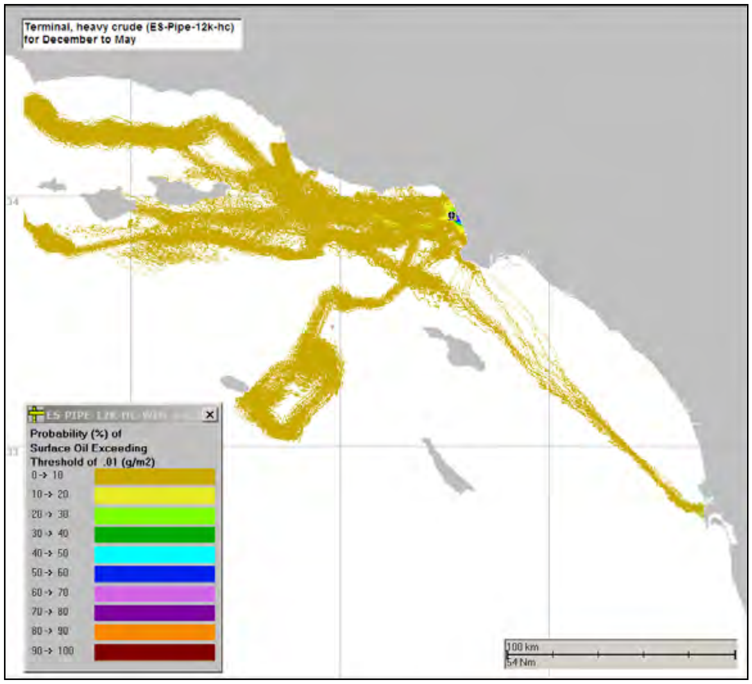

Figure C.3-9. Terminal, heavy crude (ES-Pipe-12k-hc): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for December to May.

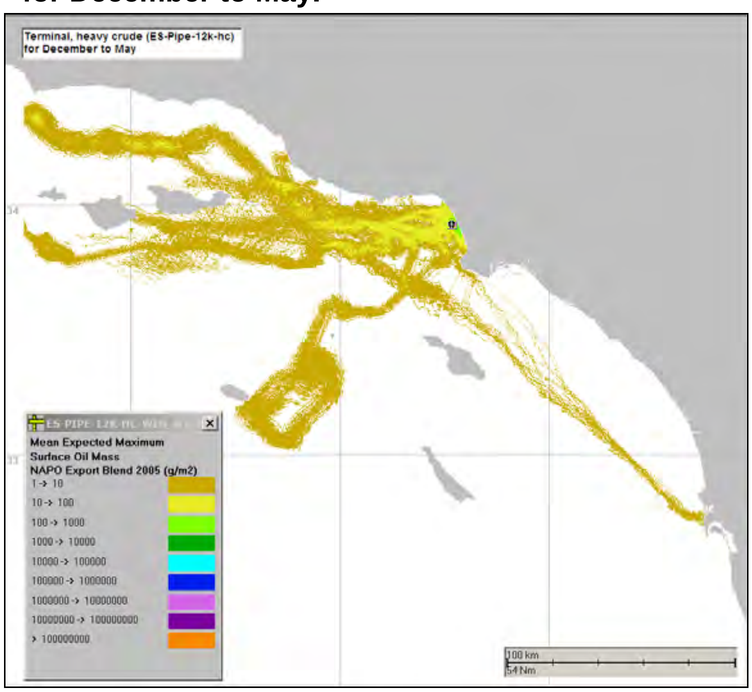

Figure C.3-10. Terminal, heavy crude (ES-Pipe-12k-hc): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for December to May.

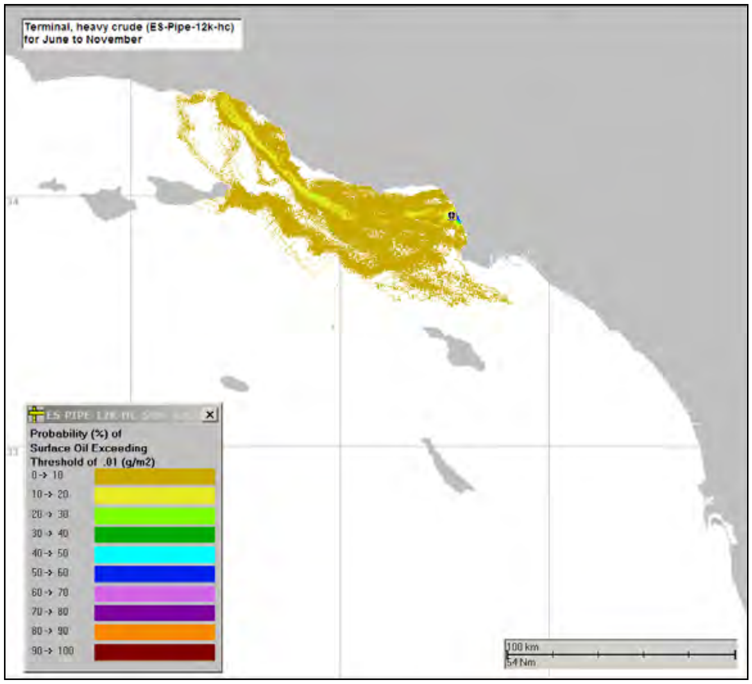

Figure C.3-11. Terminal, heavy crude (ES-Pipe-12k-hc): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for June to November.

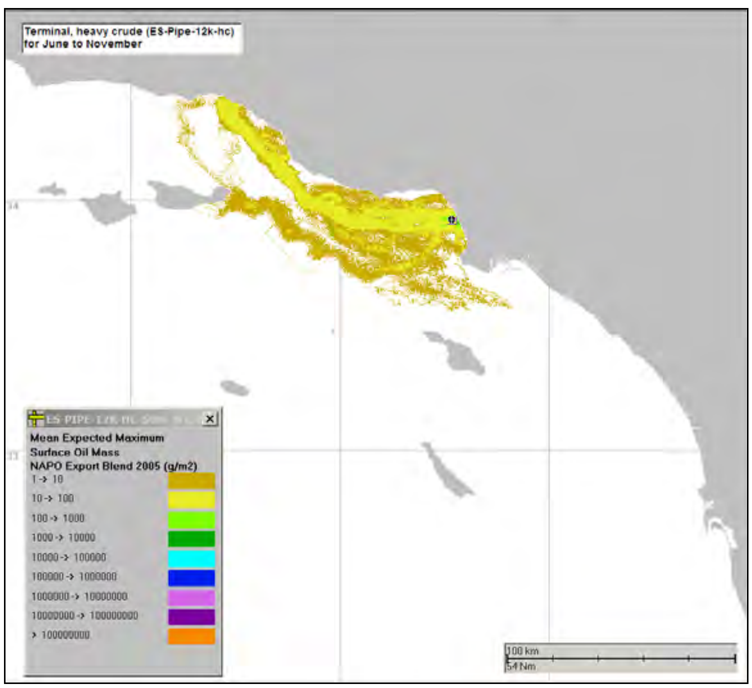

Figure C.3-12. Terminal, heavy crude (ES-Pipe-12k-hc): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for June to November.

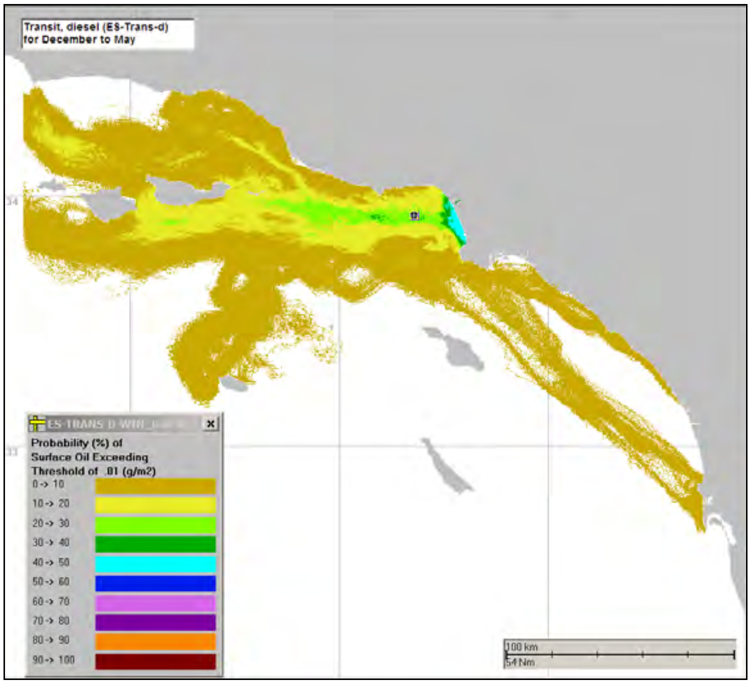

Figure C.3-13. Transit, diesel (ES-Trans-d): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for December to May.

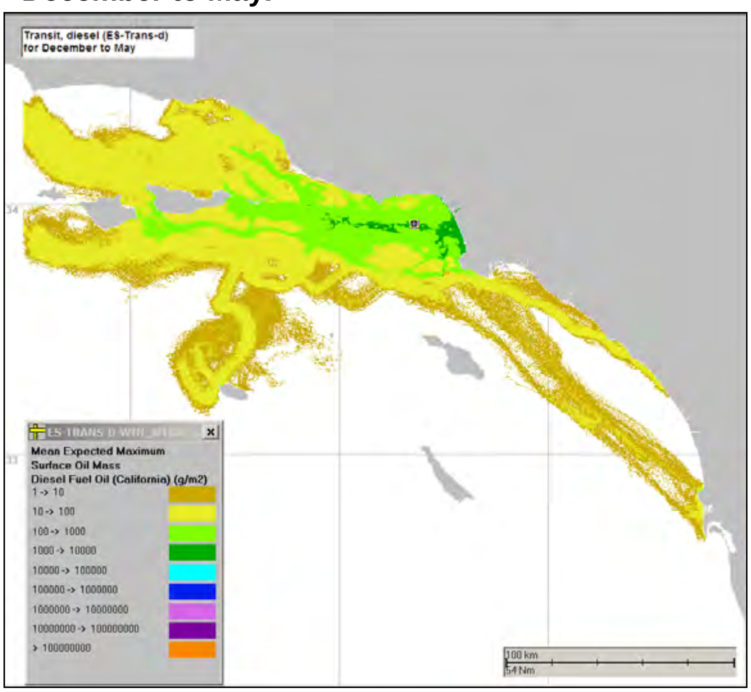

Figure C.3-14. Transit, diesel (ES-Trans-d): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for December to May.

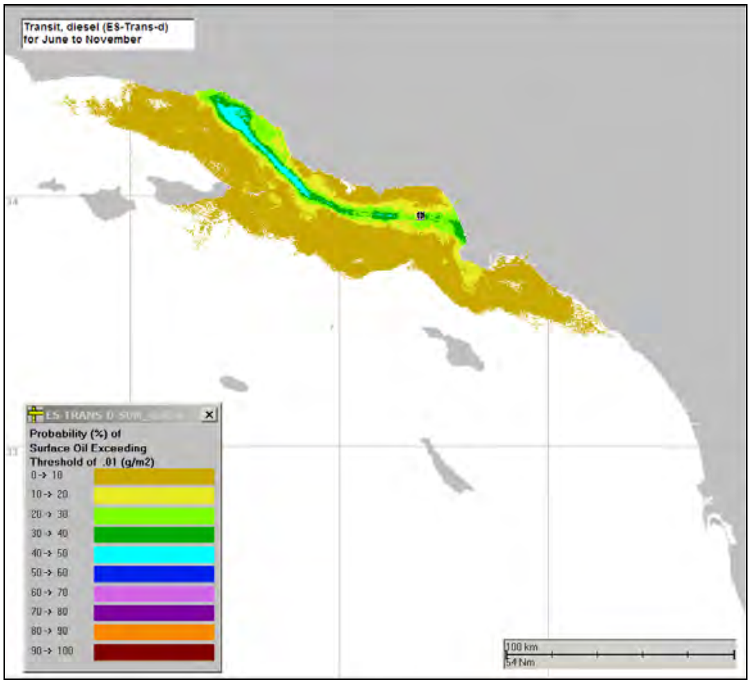

Figure C.3-15. Transit, diesel (ES-Trans-d): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for June to November.

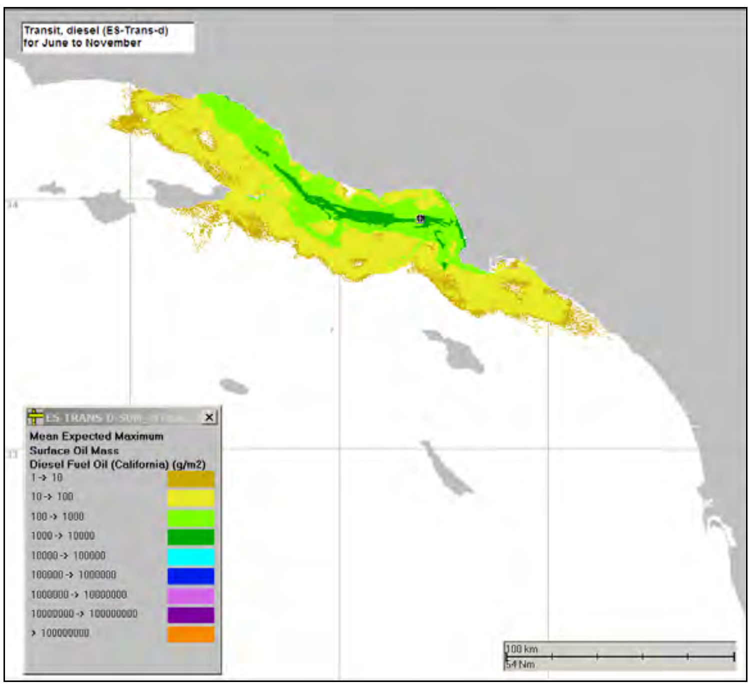

Figure C.3-16. Transit, diesel (ES-Trans-d): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for June to November.

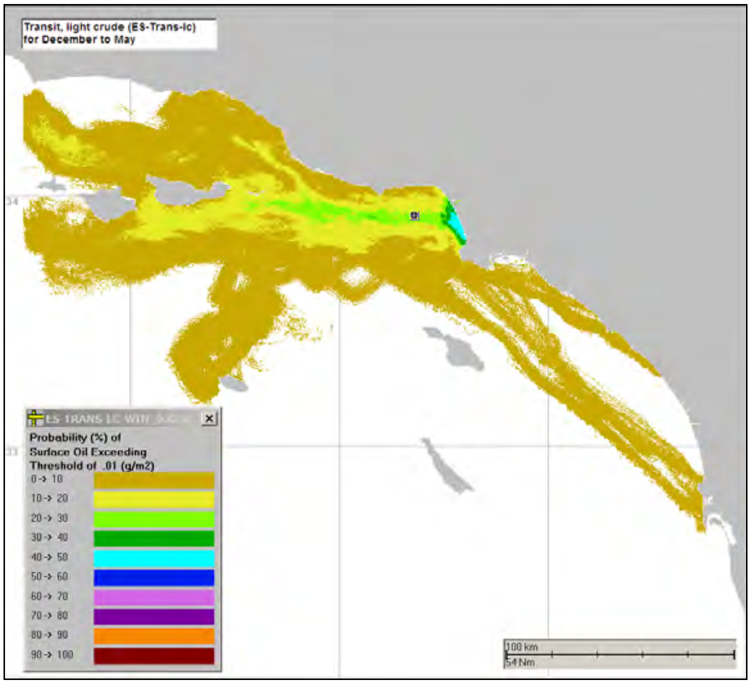

Figure C.3-17. Transit, light crude (ES-Trans-lc): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for December to May.

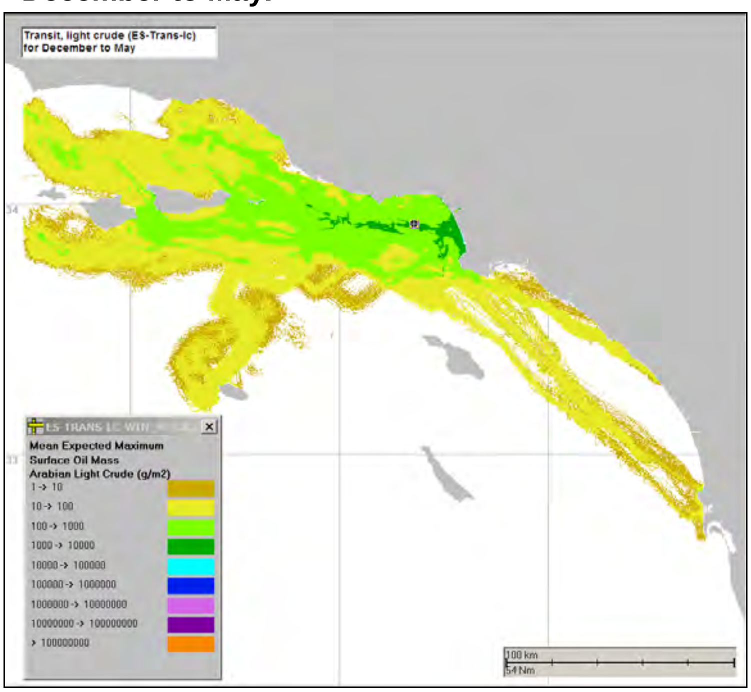

Figure C.3-18. Transit, light crude (ES-Trans-lc): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for December to May.

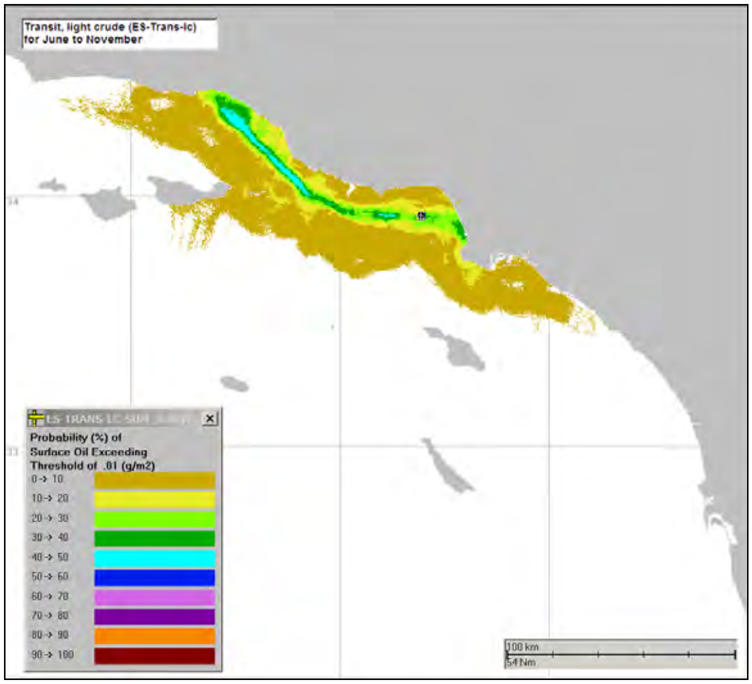

Figure C.3-19. Transit, light crude (ES-Trans-lc): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for June to November.

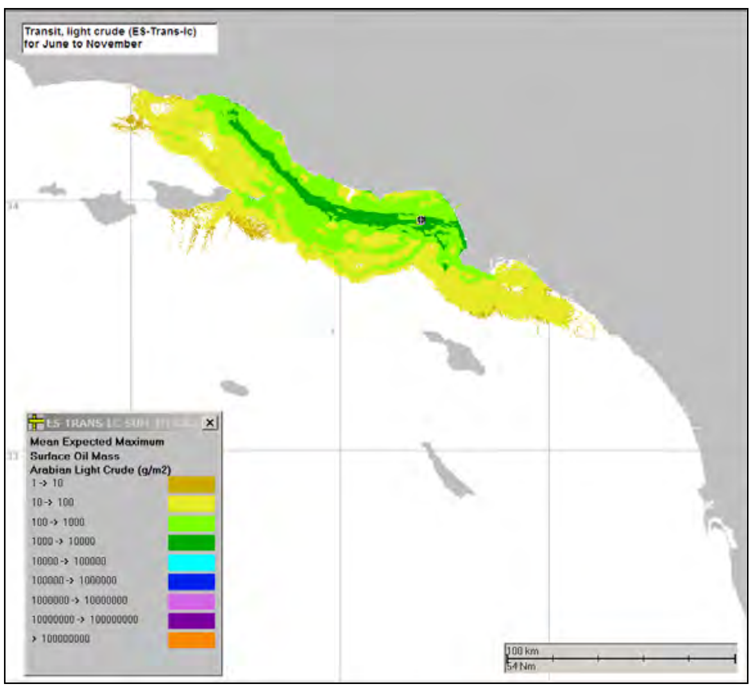

Figure C.3-20. Transit, light crude (ES-Trans-lc): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for June to November.

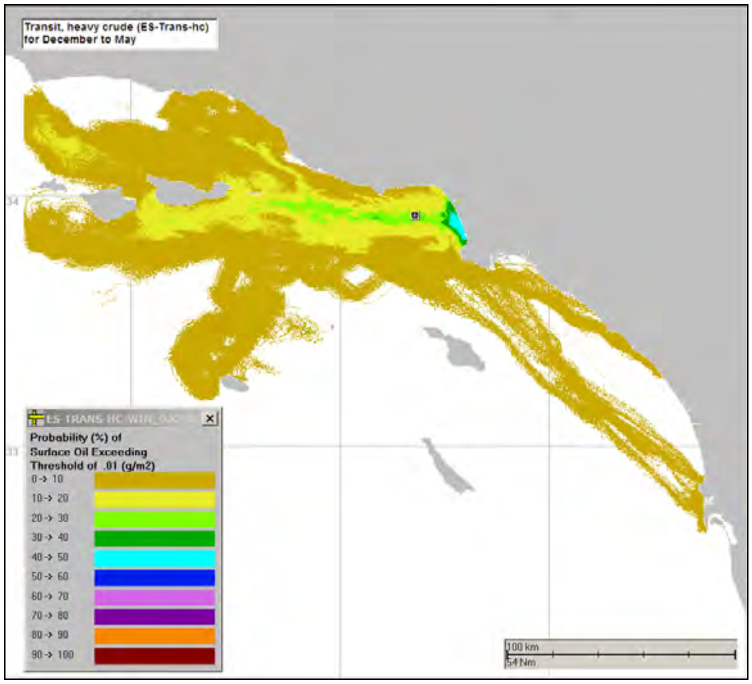

Figure C.3-21. Transit, heavy crude (ES-Trans-hc): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for December to May.

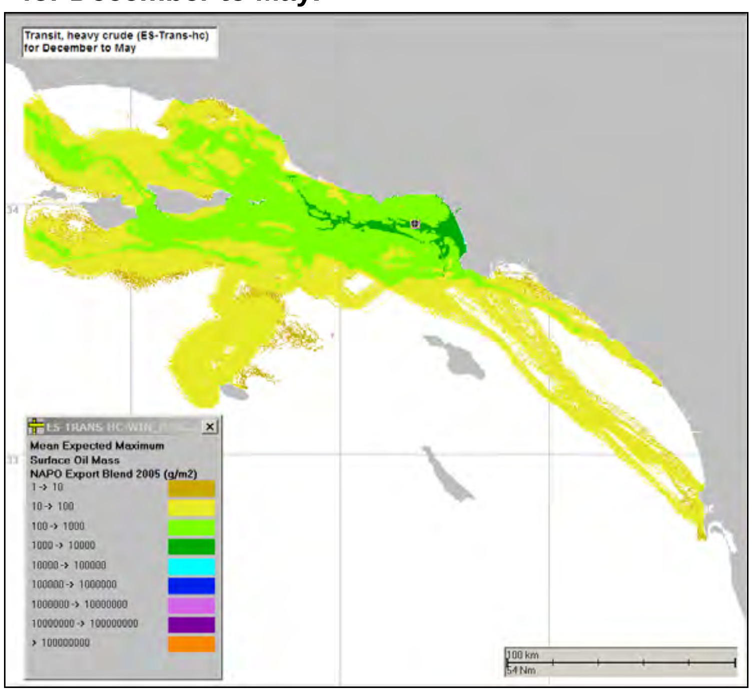

Figure C.3-22. Transit, heavy crude (ES-Trans-hc): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for December to May.

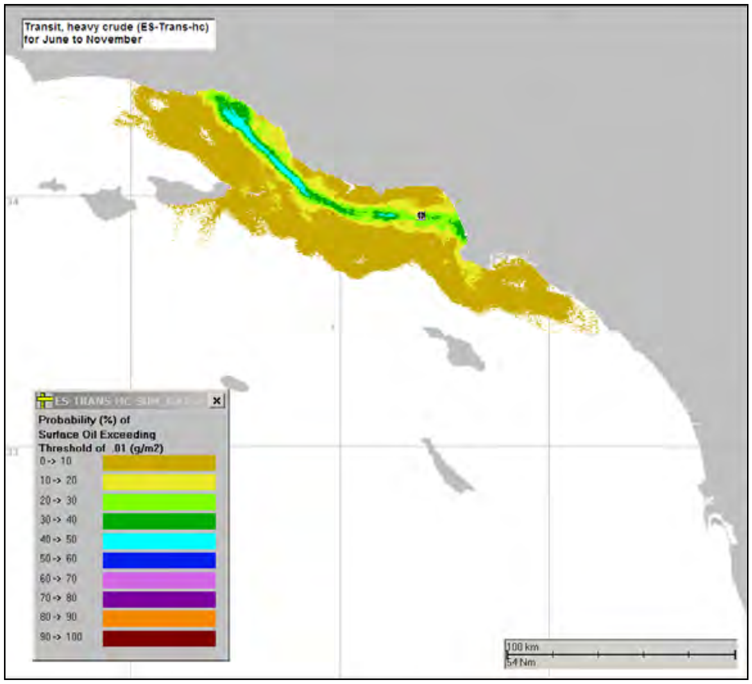

Figure C.3-23. Transit, heavy crude (ES-Trans-hc): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for June to November.

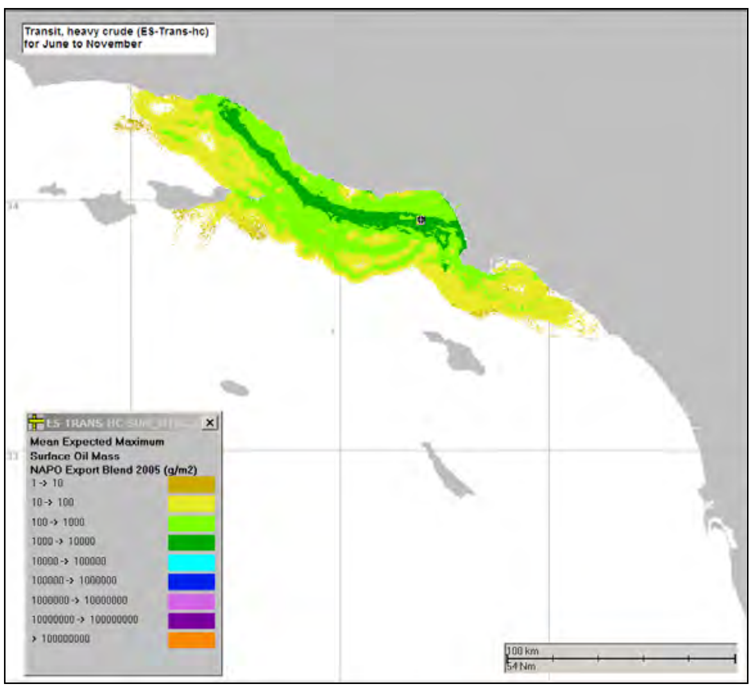

Figure C.3-24. Transit, heavy crude (ES-Trans-hc): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for June to November.

For the transit spills of 2,500 bbl diesel fuel oil, the footprint is the same as shown for the 275,000 bbl diesel spills, however the mass (g/m^2) will be 0.9% of that shown in Figures C.3-13 to C.3-16. For the transit spills of 2,500 bbl light crude oil, the footprint is the same as shown for the 275,000 bbl light crude spill, however the mass (g/m^2) will be 0.9% of that shown in Figures C.3-17 to C.3-20. For the transit spills of 2,500 bbl heavy crude oil, the footprint is the same as shown for the 275,000 bbl heavy crude spill, however the mass (g/m^2) will be 0.9% of that shown in Figures C.3-21 to C.3-24.

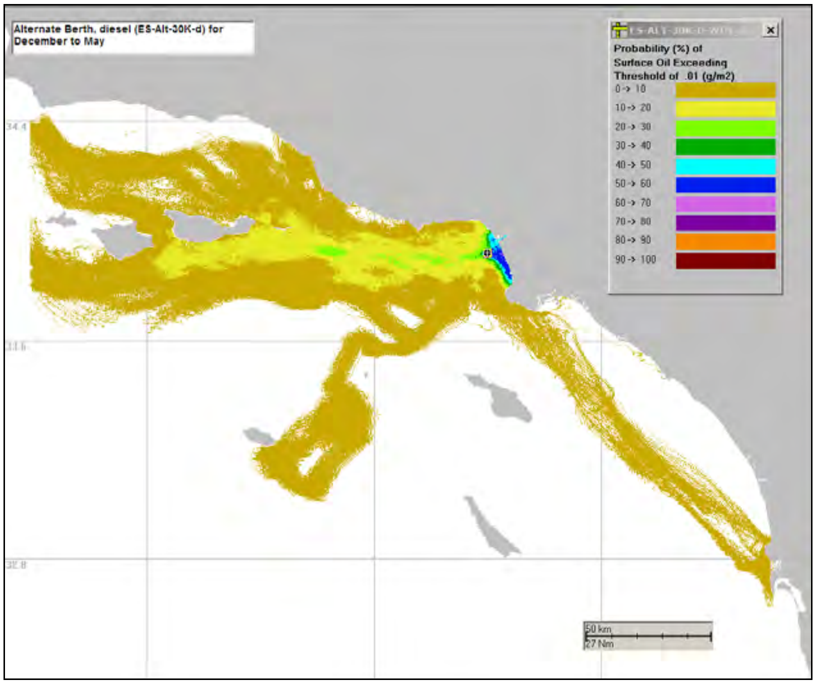

Figure C.3-25. Alternate Berth, diesel (ES-Alt-30K-d): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for December to May.

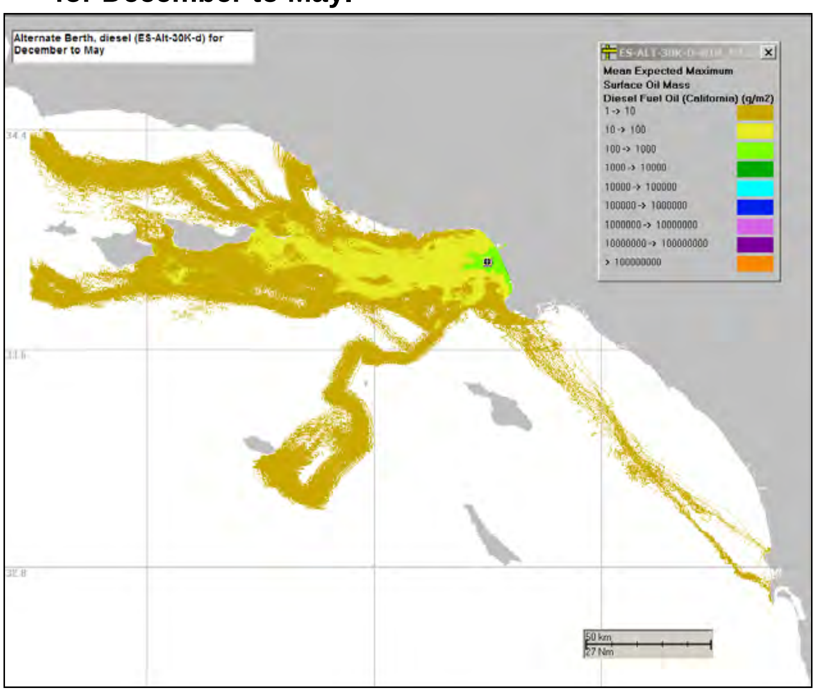

Figure C.3-26. Alternate Berth, diesel (ES-Alt-30K-d): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for December to May.

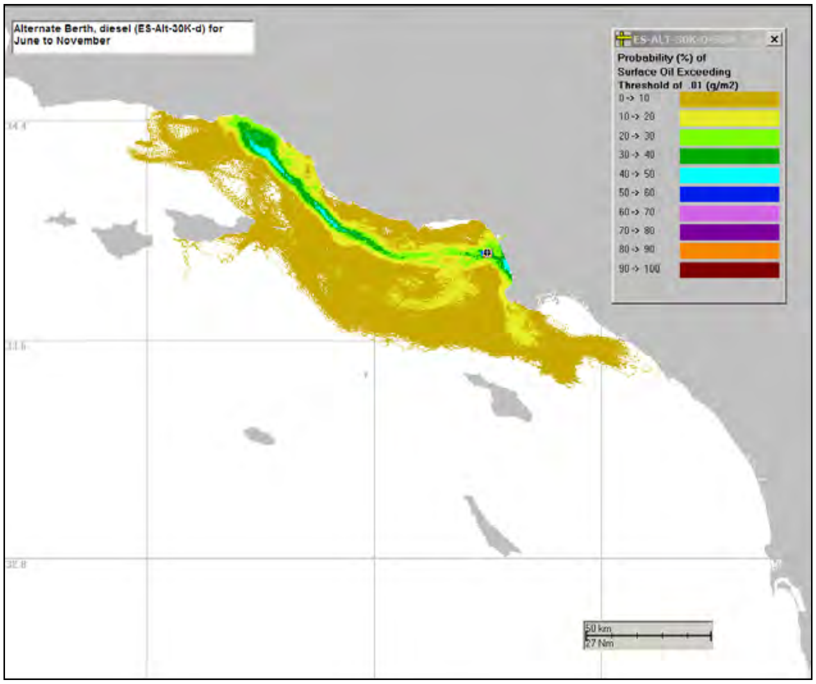

Figure C.3-27. Alternate Berth, diesel (ES-Alt-30K-d): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for June to November.

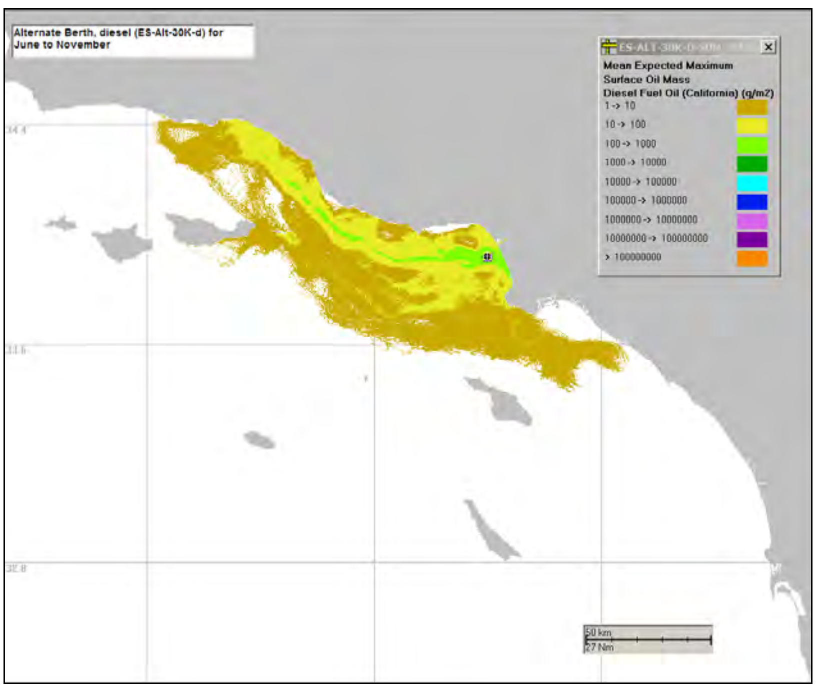

Figure C.3-28. Alternate Berth, diesel (ES-Alt-30K-d): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for June to November.

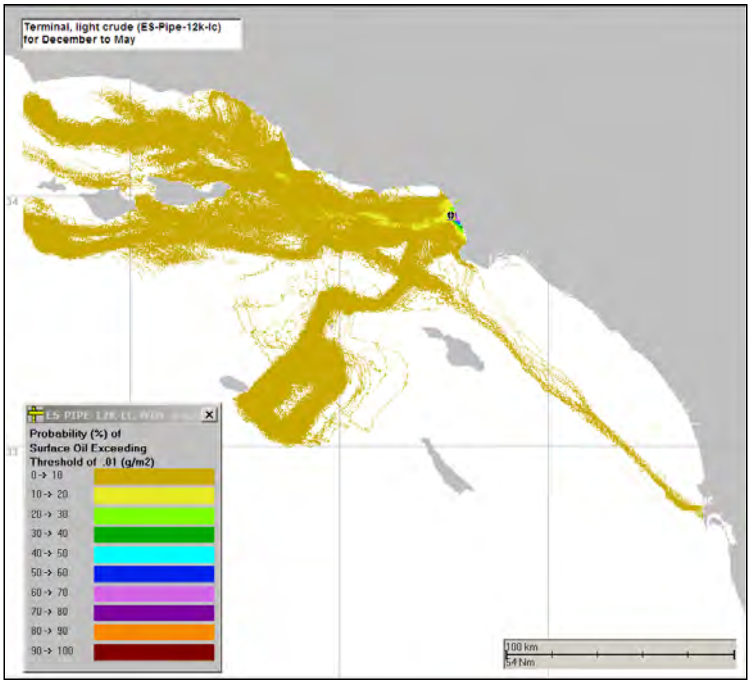

Figure C.3-29. Alternate Berth, light crude (ES-Alt-30K-lc): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for December to May.

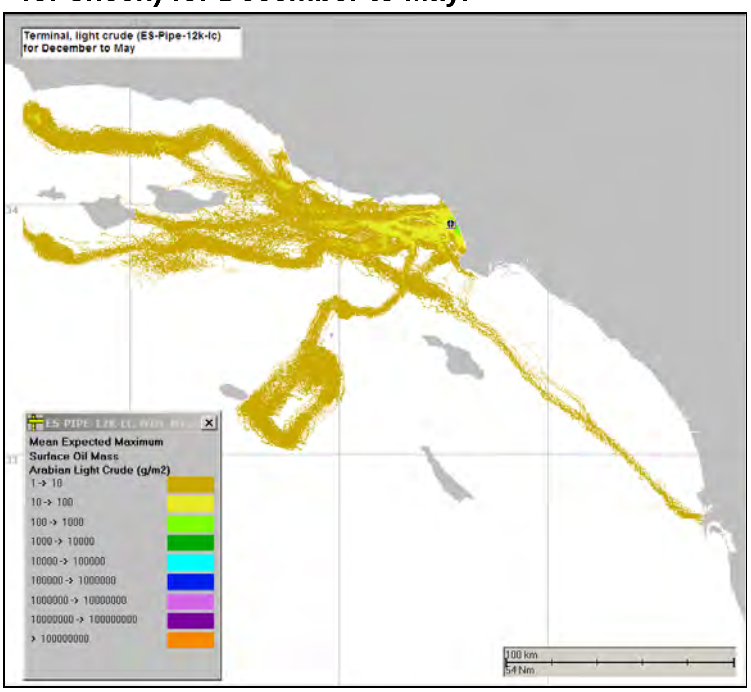

Figure C.3-30. Alternate Berth, light crude (ES-Alt-30K-lc): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for December to May.

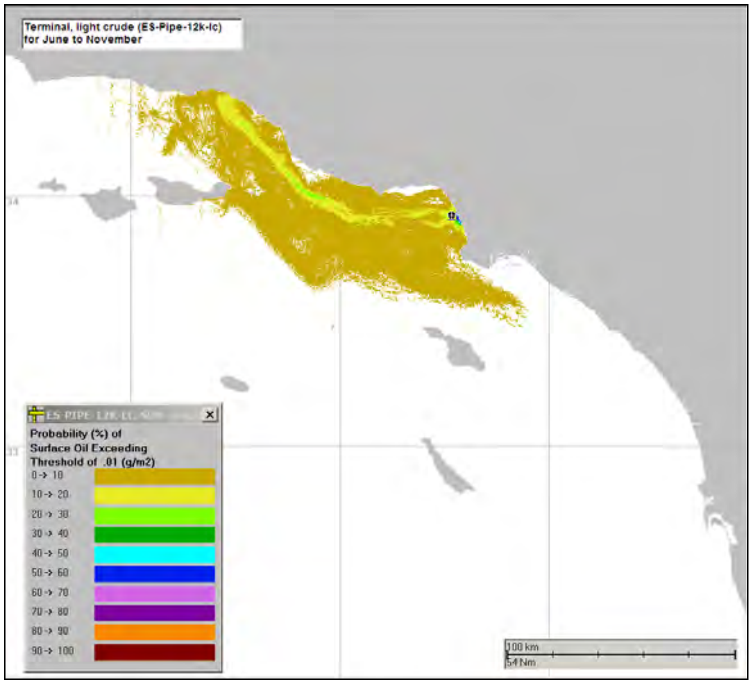

Figure C.3-31. Alternate Berth, light crude (ES-Alt-30K-lc): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for June to November.

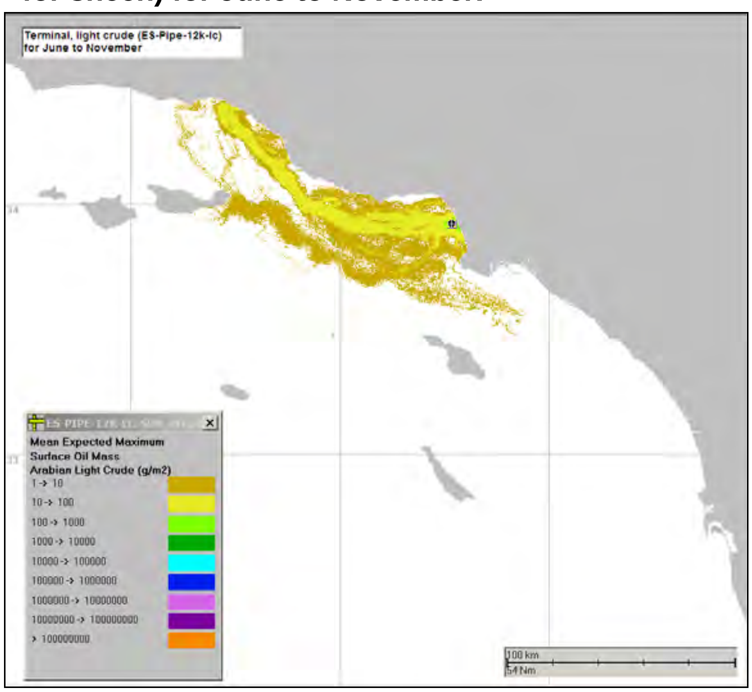

Figure C.3-32. Alternate Berth, light crude (ES-Alt-30K-lc): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for June to November.

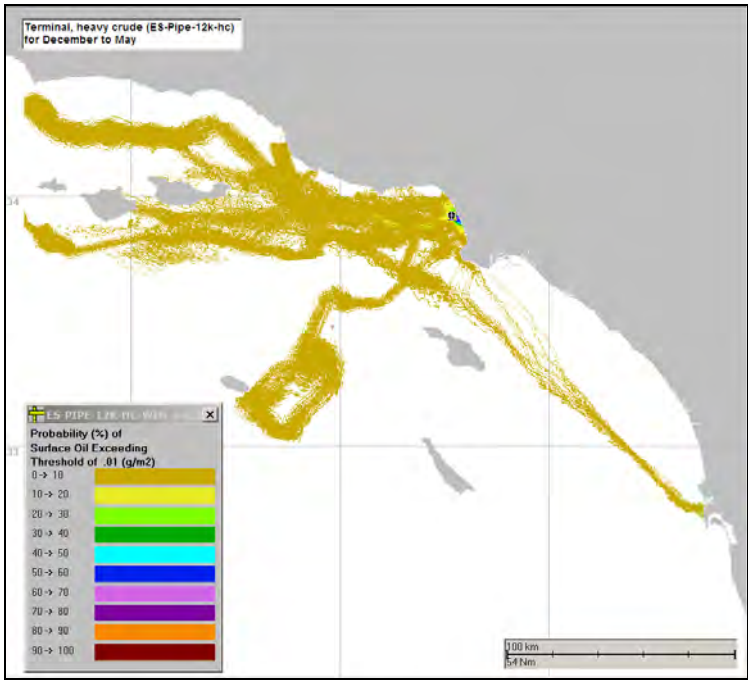

Figure C.3-33. Alternate Berth, heavy crude (ES-Alt-30K-hc): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for December to May.

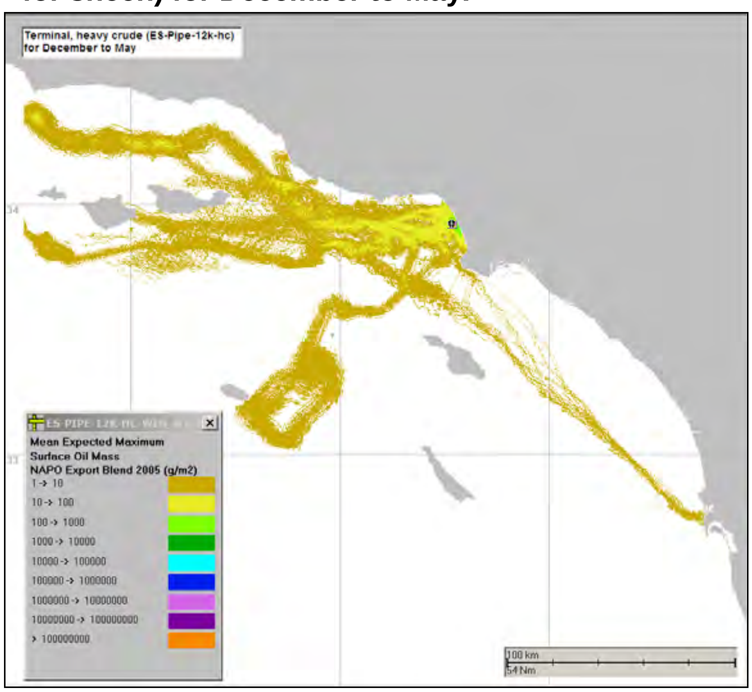

Figure C.3-34. Alternate Berth, heavy crude (ES-Alt-30K-hc): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for December to May.

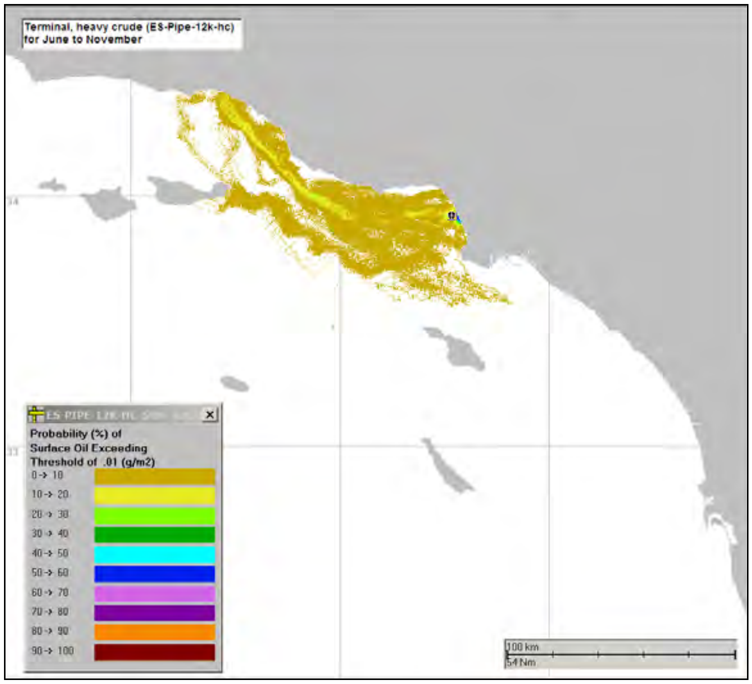

Figure C.3-35. Alternate Berth, heavy crude (ES-Alt-30K-hc): Probability (%) of surface floating oil exceeding 0.01 g/m^2 (the minimum thickness for sheen) for June to November.

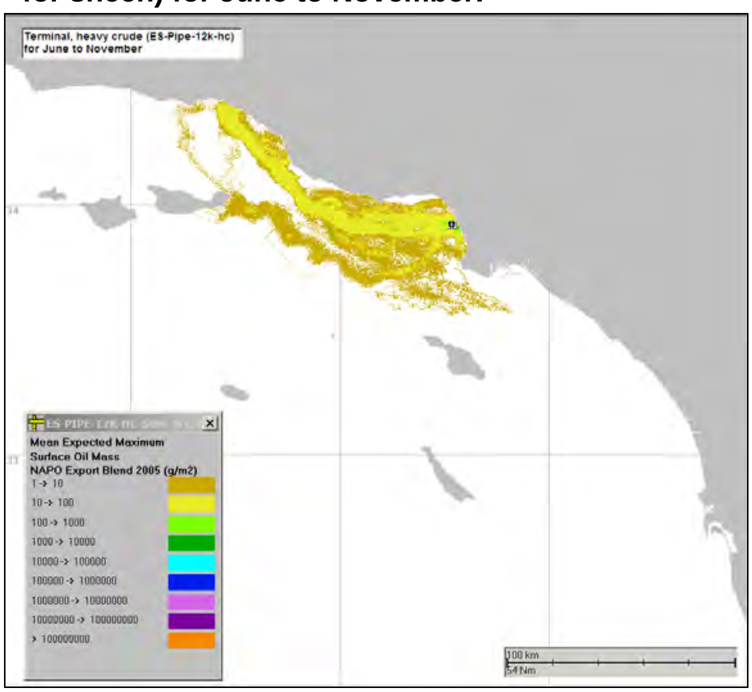

Figure C.3-36. Alternate Berth, heavy crude (ES-Alt-30K-hc): Maximum possible exposure (for any of the 100 trajectories) to floating oil (g/m^2) for June to November.

C.4 Statistics for All Model Runs

Impact indices, such as water surface exposure to floating oil, were analyzed for each of the 9 stochastic scenarios (defined in Table C.1-1). For oil on the water surface, 1 μm is approximately 1 g/m^2. Table C.4-1 gives approximate thickness ranges for surface oil of varying appearance. Dull brown sheens are about 1 g/m^2 thick. Rainbow sheen is about 200-800 mg/m^2 and silver sheens are 50-800 mg/m^2 thick (NRC, 1985). The threshold for impacts to wildlife is 10 μm (10 g/m^2). Crude and heavy fuel oil thick enough to impact wildlife is dark brown sheen or black oil. Light fuels and diesel > 1mm thick are not black in appearance, but appear brown or reddish. Floating oil will not always have these appearances, however, as weathered oil would be emulsified as mousse or in the form of scattered floating tar balls and tar mats where currents converge.

Table C.4-1. Oil thickness (microns ~ g/m^2) and appearance on water (NRC, 1985).

Minimum	Maximum	Appearance
0.05	0.2	Colorless and silver sheen
0.2	0.8	Rainbow sheen
1	4	Dull brown sheen
10	100	Dark brown sheen
1000	10000	Black oil

The following impact indices are summarized below in Tables C.4-1 to C.4.9 and Figures C.4-1 to C.4-18. The 50th and 95th percentile results were based on rank order distributions, such as those shown in Figures C.4-1 to C.4-18.

- Water surface (km^2) exposed to floating oil of various threshold thicknesses (>0.01, 1, 10, 100, and 1000 g/m^2);
- Water volume exposed to > 1 ppb (>1 mg/m^3) of dissolved aromatic concentration at some time after the spill (which is indicative of effects on water quality);
- Exposure dose of dissolved aromatics (ppb-hours) in the water volume exposed to > 1 ppb of dissolved aromatic concentration at some time after the spill (which is indicative of the potential for effects on fish and invertebrates);
- Percent of spilled hydrocarbon mass eventually going ashore;
- Percent of spilled hydrocarbon mass settling to sediments (subtidal and extensive intertidal habitats); and
- Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill.

Table C.4-2. Terminal, diesel (ES-Pipe-11k-d): Summary of on- and in-water exposure indices for 100 stochastic runs (for all seasons).

Exposure Index	Mean	Standard Deviation	Mean + 2(Std.Dev.)	Number of Zeros	50th Percentile	95th Percentile	Maximum
Surface Oil Exposure Exceeding 0.01g/m^2 (km^2), i.e., sheen	9,591	13,500	36,591	0	4,351	35,092	81,368
Surface Oil Exposure Exceeding 0.01g/m^2 (mile^2)	3,703	5,212	14,128	0	1,680	13,549	31,416
Surface Oil Exposure Exceeding 0.1g/m^2 (km^2)	9,591	13,500	36,590	0	4,351	35,092	81,368
Surface Oil Exposure Exceeding 0.1g/m^2 (mile^2)	3,703	5,212	14,128	0	1,680	13,549	31,416
Surface Oil Exposure Exceeding 1.0g/m^2 (km^2)	9,589	13,498	36,584	0	4,348	35,092	81,368
Surface Oil Exposure Exceeding 1.0g/m^2 (mile^2)	3,702	5,211	14,125	0	1,679	13,549	31,416
Surface Oil Exposure Exceeding 10g/m^2 (km^2)	6,297	9,966	26,230	0	2,298	23,582	72,057
Surface Oil Exposure Exceeding 10g/m^2 (mile^2)	2,431	3,848	10,127	0	887	9,105	27,821
Surface Oil Exposure Exceeding 100g/m^2 (km^2)	2,721	3,092	8,906	0	1,219	9,700	13,598
Surface Oil Exposure Exceeding 100g/m^2 (mile^2)	1,051	1,194	3,439	0	471	3,745	5,250
Surface Oil Exposure Exceeding 1000g/m^2 (km^2), i.e., brown/black oil	394	157	707	0	366	717	754
Surface Oil Exposure Exceeding 1000g/m^2 (mile^2)	152	61	273	0	141	277	291
Maximum Dissolved Aromatic Plume Volume Exceeding 1 ppb (m^3)	1.64E+08	3.18E+08	8.00E+08	59	0.00E+00	7.60E+08	2.21E+09
Maximum Dissolved Aromatic Plume Volume Exceeding 1 ppb (ft^3)	5.80E+09	1.12E+10	2.83E+10	59	0.00E+00	2.69E+10	7.81E+10
Average Dose of PAH's in Maximum Volume Exceeding 1 ppb (ppb-hrs)	431	646	1,723	59	0	1,736	2,656
Percent of Spilled Hydrocarbon Mass Coming Ashore (%)	18.58	5.04	28.67	1	19.90	24.04	28.35
Percent of Spilled Hydrocarbon Mass Settling to Sediments (in subtidal and extensive intertidal habitats, %)	15.4978	10.1636	35.8250	3	21.0631	25.4797	25.6437
Maximum Percent of Spilled Hydrocarbon Mass in the Water Column at Any Time after the Spill (%)	14.19	5.81	25.82	0	13.73	24.42	31.95

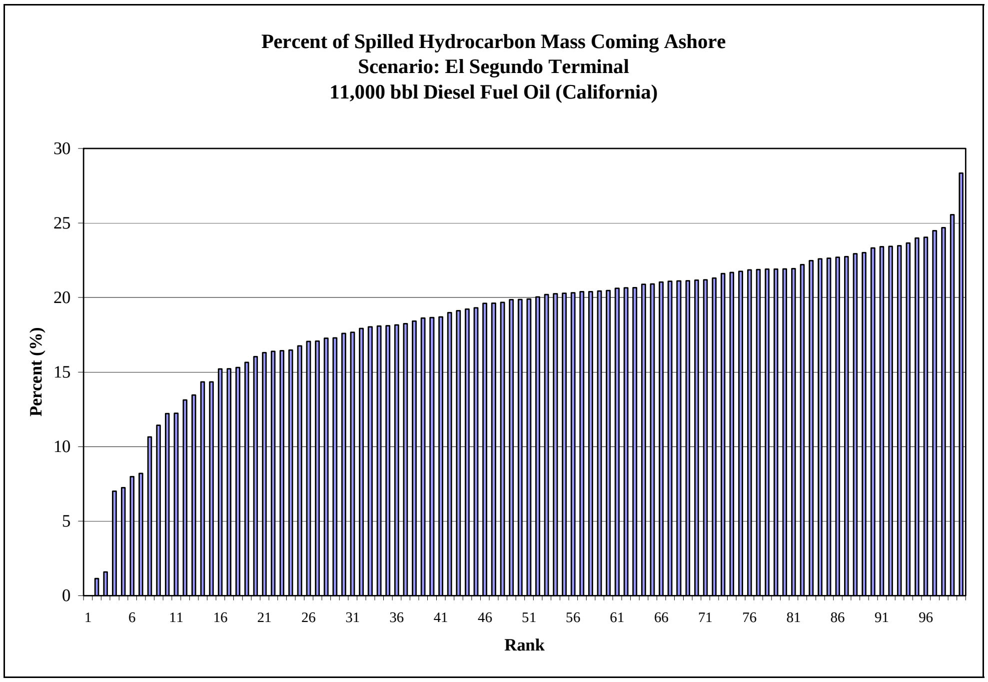

Figure C.4-1. Terminal, diesel (ES-Pipe-11k-d): Percent of spilled hydrocarbon mass eventually going ashore for runs in all seasons.

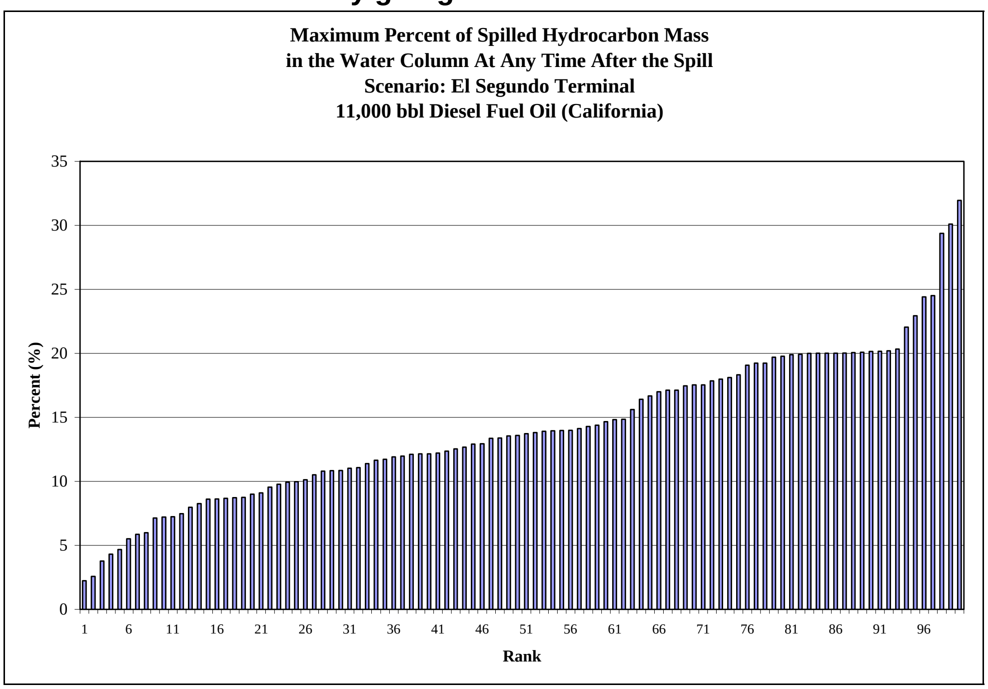

Figure C.4-2. Terminal, diesel (ES-Pipe-11k-d): Percent of spilled hydrocarbon mass in the water column at any time after the spill for runs in all seasons.

Table C.4-3. Terminal, light crude (ES-Pipe-12K-lc): Summary of on- and in-water exposure indices for 100 stochastic runs (for all seasons).

Exposure Index	Mean	Standard Deviation	Mean + 2(Std.Dev.)	Number of Zeros	50th Percentile	95th Percentile	Maximum
Surface Oil Exposure Exceeding 0.01g/m^2 (km^2), i.e., sheen	2,329	4,265	10,858	0	339	12,761	20,966
Surface Oil Exposure Exceeding 0.01g/m^2 ($mile^2$)	899	1,647	4,192	0	131	4,927	8,095
Surface Oil Exposure Exceeding 0.1g/m^2 (km^2)	2,329	4,265	10,858	0	339	12,761	20,966
Surface Oil Exposure Exceeding 0.1g/m^2 ($mile^2$)	899	1,647	4,192	0	131	4,927	8,095
Surface Oil Exposure Exceeding 1.0g/m^2 (km^2)	2,325	4,260	10,844	0	338	12,761	20,948
Surface Oil Exposure Exceeding 1.0g/m^2 ($mile^2$)	898	1,645	4,187	0	130	4,927	8,088
Surface Oil Exposure Exceeding 10g/m^2 (km^2)	2,133	3,785	9,703	0	337	12,346	15,954
Surface Oil Exposure Exceeding 10g/m^2 ($mile^2$)	824	1,461	3,746	0	130	4,767	6,160
Surface Oil Exposure Exceeding 100g/m^2 (km^2)	2,023	3,625	9,273	0	316	12,346	15,114
Surface Oil Exposure Exceeding 100g/m^2 ($mile^2$)	781	1,400	3,580	0	122	4,767	5,836
Surface Oil Exposure Exceeding 1000g/m^2 (km^2), i.e., brown/black oil	438	449	1,337	0	239	1,617	1,821
Surface Oil Exposure Exceeding 1000g/m^2 ($mile^2$)	169	174	516	0	92	624	703
Maximum Dissolved Aromatic Plume Volume Exceeding 1 ppb (m^3)	6.53E+06	3.27E+07	7.20E+07	89	0.00E+00	5.61E+06	2.14E+08
Maximum Dissolved Aromatic Plume Volume Exceeding 1 ppb (ft^3)	2.31E+08	1.16E+09	2.54E+09	89	0.00E+00	1.98E+08	7.55E+09
Average Dose of PAH's in Maximum Volume Exceeding 1 ppb (ppb-hrs)	28	124	276	89	0	213	797
Percent of Spilled Hydrocarbon Mass Coming Ashore (%)	34.69	8.34	51.37	1	37.77	41.12	42.87
Percent of Spilled Hydrocarbon Mass Settling to Sediments (in subtidal and extensive intertidal habitats, %)	26.5723	12.9423	52.4569	0	34.5109	35.5935	35.8619
Maximum Percent of Spilled Hydrocarbon Mass in the Water Column at Any Time after the Spill (%)	10.73	6.15	23.02	0	8.34	25.83	26.51

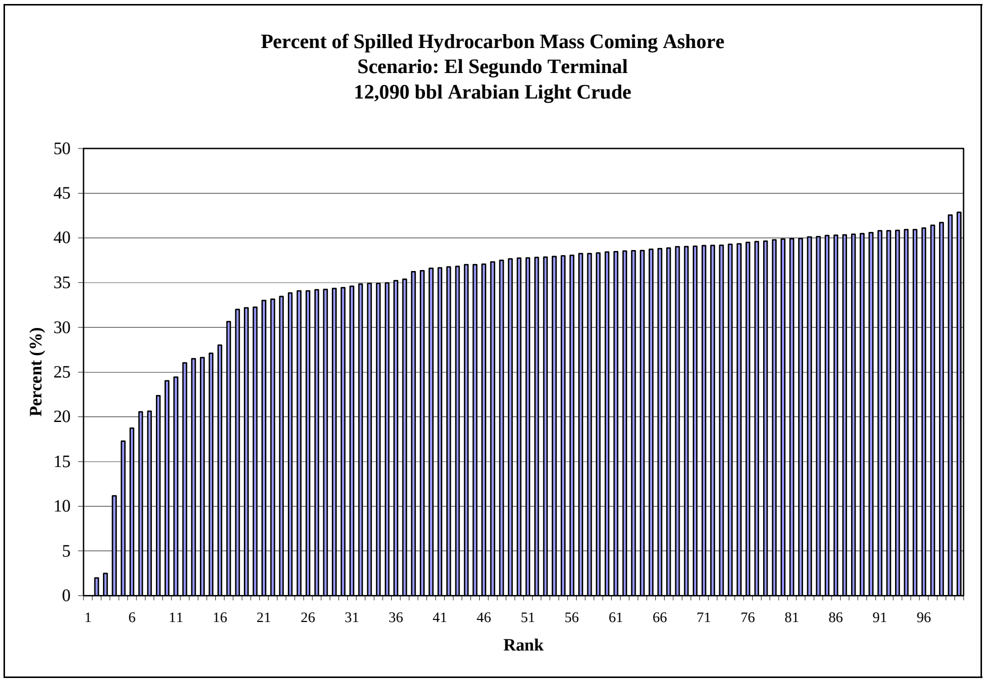

Figure C.4-3. Terminal, light crude (ES-Pipe-12K-lc): Percent of spilled hydrocarbon mass eventually going ashore for runs in all seasons.

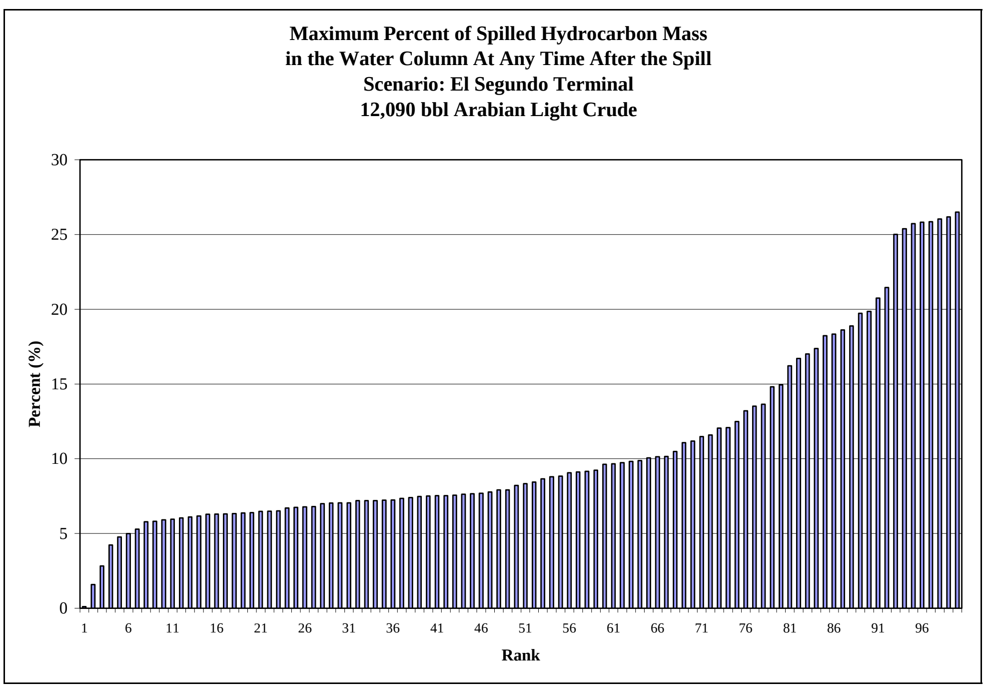

Figure C.4-4. Terminal, light crude (ES-Pipe-12K-lc): Percent of spilled hydrocarbon mass in the water column at any time after the spill for runs in all seasons.